Environmental impact of household solid waste disposal practices on plant growth in rural areas of KwaZulu-Natal: A case study of UThukela District Municipality

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Dissertation presented in accordance with the requirements for the degree of Master of Science (Environmental Science) at the University of South Africa

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Dissertation in accordance with the requirements for the degree of Master of Science (Environmental Science) at the University of South Africa
DECLARATION

I, Sabelo Abednego Khumalo, hereby declare that the master’s research reported herewith on the topic, "Environmental impact of household solid waste disposal practices on plant growth in rural areas of KwaZulu-Natal: A case study of UThukela District Municipality", is my own work and that all the sources I utilised or quoted have been indicated and acknowledged by means of complete referencing. I further declare that I have not previously submitted this work, or part of it, for examination at UNISA or at any other higher education institution for another qualification.

____________________________  ____________________
Sabelo Abednego Khumalo               Date
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ABSTRACT

The absence or unavailability of solid waste disposal facilities and service in rural areas of the UThukela District Municipality (UTDM) compelled residents to adopt many disposal practices. This included open burning of waste, which leaves residues in the form of waste ashes. Some heavy metal and hazardous substances remain active in these waste ashes. In this study, the impact of Solid Waste Disposal Practices (SWDP) on the environment was investigated by evaluating the effect of waste ashes on plant growth. The research was directed towards the evaluation of the environmental impact of solid waste disposal practices by households in these rural areas of KwaZulu-Natal (South Africa), on the growth of Zea Mays (Maize) plants. Rural maize farmers dominate the district of UTDM because it is a good agricultural area with great potential for high rainfall in summer, moderate temperatures, good soil and moderate slopes.

The method selected to achieve research objectives was the evaluation of the influence of waste ashes, as by-products of SWDP, on plant growth. This was achieved by, determining soil fertility; collecting household solid waste from different rural families to determine the composition (including already burnt ash, plastic ash and wood ash; analysing the chemical composition of traditional ashes collected from sites where it was burnt (waste ashes); applying the evaporation pan test; mixing waste ashes and other additives with soil in planting pots in equal parts; planting Zea Mays in winter and summer; and lastly, monitoring and measuring agronomic parameters of plant growth on a regular basis. The selected additives to the in situ soil were fertilizer, compost, waste ash, plastic ash and wood ash. Pots with soil only (no additive added) served as control.

The findings revealed that plants exposed to wood, waste and plastic ash struggled to grow when compared to plants grown with fertilizer, compost and soil only. The impact of all waste ashes on plant growth was negative in both seasons and some of the agronomic parameters were unable to sprout during the course of plant growth. The chemicals found after analysing the waste ashes included some of the heavy metals that remained active after burning. These were left behind in the environment. Consequently, it was concluded that household solid waste disposal practices in rural areas should be reviewed urgently, as they affect plant growth negatively. Recommendations were provided.

Key words: Solid waste disposal; UThukela District Municipality; Zea Mays; Plant growth; Additives.
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1.1 INTRODUCTION

Solid waste disposal has always been a chronic problem in rural areas causing serious environmental problems (ELARD, 2009). The illegal dumping and burning of household solid waste are the most common disposal methods practised in the rural areas of KwaZulu-Natal (IDP, 2011). These practices result in environmental problems such as serious land, water and air pollution (Nkwachukwu et al., 2010). People in rural areas dump their waste indiscriminately on roadsides and on any available open pit irrespective of the impact to the environment (Kaundal & Sharma, 2007). Illegal dumping has been banned because of its adverse impact and has been widely documented. Nevertheless, in rural areas the practice is still common and even in some urban areas mainly due to lack of law enforcement, financial means and awareness (Frantz, 2006; ELARD, 2009).

Solid waste refers to the unwanted and useless solid materials generated from residential, industrial and commercial activities in a given area (Frantz, 2006; Post, 2007; ELARD, 2009). It may be categorised according to its origin, namely household, industrial, commercial, or construction. However, solid waste often contains harmful substances, which may be hazardous to human health and to the environment (Frantz, 2006), containing batteries, paints, plastic water bottles, wine bottles, light bulbs, polythene bags and many items used in daily life (Post, 2007). However, these waste products decompose and result in the deposition of chemicals in low concentration into the environment (Mahmoodabadi et al., 2010). This study focuses on the effect of household solid waste disposal practices in the rural areas of UThukela District Municipality (UTDM).

In most developing countries, where this practice is common, the indiscriminate disposal of solid waste practices is not conducive to public health or to the environment (Frantz, 2006). Poor waste management practices can have an adverse impact both locally and globally (ELARD, 2009). However, the generation of waste must be avoided, or where it cannot be avoided, it must be reduced, re-used, recycled or recovered. Only as a last resort can it be treated and disposed of safely (Uzair et al., 2009).
Improper waste management has resulted in undesirable environmental problems to people and this has seriously affected lifestyles and the living environment of the future generations (Pingoud & Wagner, 2006). Moreover, the indiscriminate disposal of municipal solid waste produces significant amounts of methane (CH₄), biogenic carbon dioxide (CO₂), carbon monoxide (CO) and nitrogen oxides (NOx), which are the greatest factors causing pollution in an environment (Pingoud & Wagner, 2006). Yet, it is recommended that municipal solid waste be disposed of in engineered landfill sites, which can reduce or eliminate the risk of methane production (Pingoud & Wagner, 2006).

The problems of disposing waste, whether solid, liquid or gas have the potential of polluting the water ultimately. The polluted water directly affects soil, agriculture fields, as well as riverbeds, and creates a secondary source of pollution (Uzair et al., 2009). The studies of Siciliano and Germid (1998) indicated that an open dumping site is known to contain a variety of contaminants that can influence the plants negatively. However, worldwide the increasing amount of municipal waste produced is an environmental problem (Li et al., 2006).

Burning of waste is a popular option for waste disposal in areas where there are no waste collections. Burning or the thermal treatment method is a process that uses heat to treat waste, and is commonly used in rural areas whilst causing smoke and other emissions to be released directly into the air (Post, 2007; Uzair et al., 2009). This waste treatment method, the burning of waste, produces ash as residues. The people in rural areas manage this ash in their gardens by spreading it indiscriminately in the garden or veldt. Traditionally waste ash from the wood fires (potassium) used to cook food, was used to enhance the quality of the soil; the use of this practice continues (Post, 2007). The commonly used final waste disposal practices in most rural areas of UThukela district municipality is the burning of waste.

1.2 BACKGROUND

Magaji (2012) indicated that waste generated in developing countries receive poor attention. This means that the effectiveness of handling waste in terms of collection and disposal remains undesirably low. Yet waste generation tends to increase with the increase in population and economic growth (Magaji, 2012), which together add up to the problem of responsible and effective waste management.
Household solid waste does not only contain 'valuable' and often re-usable materials (such as glass, plastic and food remains), but also contains increasing amounts of dangerous substances (Magaji, 2012). It is observed that the disposal and management of solid waste has become the number one serious environmental problem facing developing countries (Magaji, 2012), because of the consequence of the effects on the pollution of soil, water and air. According to Tapong (2002), the predominant method of waste disposal in rural areas of developing countries is uncontrolled dumping in open veldt or unsanitary landfills. There are many problems associated with this method, such as release of CH$_4$ and CO$_2$ (regarded as greenhouse gases), contamination of ground water by leachate from decomposition of waste and the contamination of soil with waste ash.

Soil is the most polluted part of the dumpsites, and thus affect soil quality and plant growth. Burning of waste leaves a bulk of ash, which is the residue of this method. This ash becomes problematic to manage by the community therefore; poor handling of this ash has negative effects on the soil in particular, because it is composed of various chemicals depending on the composition. Various studies of the Institute for Soil Fertility (1988), Nagendran et al. (2011) and Magaji (2012) have been conducted to evaluate the implication of metal contamination absorbed by plants in relation to soil pollution and atmospheric deposition on the soil surface. Contaminants, such as heavy metals, acid mine, cyanides, radioactive substance and pharmaceuticals products were evaluated in the study of Nagendran et al. (2011). The impact of metal contamination in agricultural production systems particularly plant growth is of great concern (Anyasi, 2012).

1.3 RESEARCH PROBLEM

UThukela District Municipality (UTDM) is a good agricultural area in the province of KwaZulu Natal because of high rainfall in summer, moderate temperature, fertile soil and moderate slope (Basson, 1997). It appears that, the fertility of the land has deteriorated in the past decades (Basson & Rossouw, 2003) and from personal observation as a resident of this area from 2007 to 2011. People in rural areas dispose their household solid waste by the open burning method and the burnt waste contains all kinds of material depending on the waste composition. The residue is ash, which has a negative impact on the plant growth because some of the heavy metal and hazardous substances remain active (Uzair et al., 2009). People use the burnt ash as fertilizers in their gardens and many people in rural areas believe that all kinds of solid waste make the land fertile rather than toxic. At UTDM, there is a lack of waste
removal services especially in rural areas. Wastes are being dumped in the vicinity (so-called unauthorised dumping sites) in open designated areas; this is then burnt to reduce the volumes. Because of this practice, the biodiversity of the area is being affected (Šmejkalova et al., 2003).

1.4 HYPOTHESIS AND OBJECTIVES

It is hypothesised that the prevailing waste disposal practice in the rural areas of UThukela District Municipality, which is the burning of waste in open dumps, contamination of the soil with the waste ash containing, *inter alia* toxic chemicals and has the potential of having a negative impact on plant growth.

The objectives of this study are:
1. To determine waste characterisation of household waste;
2. To study the effect of disposing ash (of household solid waste) on plant growth, such as maize;
3. To determine the current soil fertility of the study site;
4. To study and analyse the toxicity and composition of ash collected from households;
5. To establish ways and means to improve the management of solid waste to effect reduction, re-use, recycling and recovery.

1.5 SIGNIFICANCE OF THE STUDY

Research has reported that an increase in urbanisation and the population numbers in most parts of the developing countries have played a vital role in the escalating rate of waste generation (Tshivhandekano *et al.*, 2013). The disposal of household solid waste is an ongoing problem in the rural areas of KwaZulu-Natal (KZN) particularly in the UTDM. In this district, due to financial limitation, local municipalities of the UTDM are unable to collect waste from certain rural areas, which are a far distance from the town, and are governed usually by the traditional authority. This is because there is no revenue collected by the municipality in rural areas, whilst all services are expected to be rendered by them (IDP, 2011).

Many tons of solid wastes are generated in the rural areas of KZN annually (IDP, 2012) and the Municipalities have a limited number of scientific landfill sites. At UTDM, for instance, there is only one scientifically operated landfill (IDP, 2011), which is also situated at urban
area. Subsequently, this situation influenced people in rural areas to use various disposal practices that are not environmentally friendly.

It is clear that environmental awareness in the rural areas of KZN, particularly UTDM, has not been facilitated efficiently. By looking at the drastic rise of the household solid waste volume generated for the period of a week (during collection of waste), it was noted that it creates serious threats to health and the environment if this situation remains unsolved. Hence, this led people to adopt different waste reduction methods like re-use, repair, burning, etc. However, the method used most was burning of waste; they simply apply this method because it is cheap, not very time-consuming and easy to do.

Gakwerere (2012) indicated that burning household solid waste generally produces significant amounts of polluting flue gases, and gives rise to toxic solid residues, which subsequently have a negative impact on the environment. People of UTDM do not demarcate, protect or cover their burning site (disposal area) as can be seen in Figure1.1.

![Burning of Waste](image)

**Figure 1.1  BURNING OF WASTE**

The residue of this disposal practice is ash, which is not controlled or monitored and is just left on the site. The ashes on these open burning sites are left to be distributed to the surrounding areas by wind, thus influencing the soil quality. The people only concern themselves with lessening waste volume. With regard to the ash, some throw it in the garden and veldt as a "fertiliser", with no understanding of the chemical composition of these ashes. Yet there are a number of chemicals, which tolerate heat and as a result remain present in the
ash. Additionally, by means of wind, the ash ends up in the gardens and veldt. Hence, the contamination of this ash and soil may have an effect on soil fertility and automatically on plant growth and production. The plastic ash and also wood ash (potash) which is the residue of wood burning when cooking, are not monitored or controlled, and are being dumped indiscriminately by the people.

Over and above, the provincial government of KZN introduced the system of "one home one garden" in the province (KZN Legislature, 2009). Most of the communities of UTDM have communal gardens, and some have home gardens, where they plant maize and vegetables. These types of gardens are important because many people are unemployed and they depend on agricultural products for a living. On the other hand, some rural farmers indicated that, they had noticed that, fertility of the land in terms of production is not as good as it was before. However, this proclamation has been the one that has resulted in the intention to undertake this study. The purpose is to evaluate the environmental impact of the disposal practices on plant growth, particularly at rural areas where collection and waste management is poor. Apart from this, it would address waste reduction methods, such as recycling, reuse and composting, which could be applicable to them.

1.6 METHODOLOGY

1.6.1 Methods and techniques
Various research methods were applied in this study, in order to achieve the research objectives. The evaluation of plant growth against the waste disposal practices in rural areas was assessed by:

- Determining the soil fertility in order to reveal the composition of existing minerals and nutrients in the soil;
- Collecting household solid waste, already burnt ash and wood ash from the rural community;
- Planting *Zea mays* in the planting pot in protected gardens in different soil mixes;
- Analysing the chemical composition of traditional ash by an accredited laboratory to reveal all chemicals that can contaminate soil;
- Monitoring and measuring plant growth regularly.

Determining soil fertility was done at Cedara College of Agriculture, KwaZulu-Natal Province. Soil samplings were made in the study area and sent to the laboratory. The soil was
collected according to Cedara standard procedure of soil sampling. The chemical composition analysis of solid waste ash was done at ALS Global laboratory, which is accredited by SANAS. This test was done to screen all chemicals, which remain present in the ash and capable of contaminating the soil and plant uptake.

A small garden was designed for the purpose of the study. Plant seed was sown in the planting pots and the effect of traditional ash available in rural areas of UTDM was tested to monitor plant growth. Ash used includes wood ash (potash), plastic ash and ash produced by households when they burn their solid waste (waste ash). Fertilizer prescribed by the laboratory, commercial compost and plants/seeds planted without any additives served as control for the study. Managing of solid waste in rural areas of UTDM by the means of reduction, re-use, recycling and making compost were evaluated throughout the community of UTDM. This was completed with the assistance of Ward Councillors and Izinduna (Representative of Tribal authority). It was carried out at the Imbizo (conference), which normally and often is called by Izinduna. This conference aims to address issues that affect the community.

1.6.2 Data analysis
The results obtained include household waste from rural communities of UTDM, soil fertility results, planting and monitoring of plant growth in the planting pot, measurement of selected agronomic parameters and a chemical analysis of the waste ash. The data were analysed using different programmes of Microsoft Office.

A literature review was conducted to critically assess and evaluate all disposal methods that exist in rural areas of KZN. All disposal practices available in rural areas of UTDM were documented. The baseline information about the study site/area was included in the literature review. The effect of predominant disposal practices on plant growth was investigated and reported.

1.6.3 Description of the study area
UThukela District Municipality (UTDM) is one of ten district municipalities in the Province of KwaZulu-Natal and consists of five local municipalities, namely Okhahlamba, Indaka, Umtshezi, Imbabazane and Ladysmith Local Municipality (LM). The location and situation of these municipalities are indicated in Figure 1.2.
UTDM derives its name from one of the major rivers called UThukela in the Province of KwaZulu-Natal. The UThukela River arises from the Drakensberg Mountains and supplies water to a large portion of KZN, as well as Gauteng. The size of the UThukela District Municipality is approximately 11500km² (IDP, 2010). It is located in the western boundary of KwaZulu-Natal. It is predominately rural, with three of the five local municipalities being rural based are Okhahlamba, Indaka and Imbabazane.

According to Basson (1997), UTDM has good agricultural potential due to a combination of high rainfalls, moderate temperatures, good soils and moderate slopes. However, moderate to restricted agricultural potential occurs where acidic soils, extreme temperatures and rainfall, high hail tendencies, difficult topography and population pressure adversely affect productivity. Due to steep slopes and soil conditions, erosion is also a recurring problem (IDP, 2010).

This study was conducted at UThukela District Municipality (Figure 1.2), particularly at the Okhahlamba and Imbabazane local municipalities. These local municipalities are rural based areas, with usual high rainfall and moderate temperature at summer, which is favourable environment for plant growth. In addition commercial farming is the predominant economic activity in the area (Okhahlamba and Imbabazane local municipality), however maize, beans, butternut and cabbage are common plants cultivated in the area.
1.7 CONCLUSION

It is the intention to produce a report of the research findings to local municipalities of UThukela District municipalities on possible ways to manage solid waste disposal based on a baseline study of the local municipality and surrounding areas.

The implication of solid waste disposal on the environment would be revealed to the people in the surroundings of the municipality. This study should assist and motivate the community to reduce the quantity of organic matter deposited and encourage the community in the whole district of the municipality to apply recycling and composting automatically. The burning of solid waste in the rural areas needs to be reduced or ceased if possible, when the people realise what the impact solid waste could have on their plants. This refers particularly to plant growth and to the environment, because the burning of solid waste creates a secondary source of pollution, which could result in health hazards through the food chain (Tu et al., 2000).

1.8 SEQUENCE OF CHAPTERS

The remaining chapters are organised as follows:

Chapter 2 provides a review of the literature to outline the background of the study pertaining to household solid waste disposal and management practices, implication of waste disposal practices on the environment and the effect of waste disposal to plant growth.

Chapter 3 outlines the methods of data collection and techniques used to conduct the study and to achieve the research objectives.

Chapter 4 consists of the results and includes a discussion of the main findings, which relate to the composition of the solid waste collected, the soil fertility and a chemical analysis of the waste ash and its impact on plant growth.

Chapter 5 concludes with a summary of the main findings and the major conclusions, as well as offering recommendations for intervention and for future research.
Chapter 2
LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides a review of previous work completed regarding the effects of waste disposal practices on the environment. All disposal practices available at the rural areas of the UThukela District Municipality (UTDM) are presented in this chapter. Information that enables readers to acquire a critical understanding of the consequences of solid waste disposal practices in retarding plant growth will be provided. Furthermore, plant nutrients and plant growth processes, as well as the background related to chemical analyses of household waste are discussed. It also offers information about integrated waste management strategies that are conducive to environmental friendly practices.

The inadequacies of solid waste disposal, management and its associated problems have been key issues that have attracted research. Freduah (2002) indicated that according to a United Nations Conference report of 1996 on Human Settlement, it is estimated that about 83% of the population in developing countries dump their refuse in either authorised or unauthorised sites due to their weak capacity to handle solid waste. United Nations Conference report of 1996 agree on the matter that municipal solid waste management practices are considered inefficient in developing countries. This is confirmed by Karija et al. (2013) especially relating to collecting, processing and disposing because of irregular collection services, crude open dumping and burning without air. Solid waste management is one of the critical functions that need to be performed by a municipality. Failure to perform this function could lead to an outbreak of various infections, pollution and subsequently cause degradation of the environment (Maluleke, 2014).

The Constitution of South Africa (1996) documented that everyone has the right to a clean and protected environment for the benefit of present and future generations, through reasonable legislative and other measures that would secure ecologically sustainable development. Yet the greatest challenge facing the district municipalities of the KwaZulu-Natal Province is poor waste management. This is attributed to the fact that most of the municipalities in the province do not have permitted landfill sites (Phelamanga Projects,
Hence, the issue of waste disposal is of the utmost importance for all municipalities, as it is the leading factor of waste problems. In addition to the poor collection of waste and the absence of proper dumpsites in the rural communities, people adopt alternative disposal practices that are not favourable to the environment (Naidoo, 2009; IEP, 2010).

2.2 STUDY AREA

The UTthukela District Municipality (UTDM) is one of the eleven district municipalities in the Province of KwaZulu-Natal (KZN), which consists of five local municipalities, being Okhahlamba, Indaka, Umtshezi, Imbabazane and Ladysmith Local Municipality (LM). UTDM was established during the transformation of local government in the year 2000. UTDM derives its name from one of the major rivers called UTthukela in the Province. The UTthukela River originates in the Drakensberg mountains and supplies water to a large portion of KZN, as well as Gauteng. Three district municipalities, namely Amajuba, UMzinyathi and UMgungundlovu (IDP, 2009) surround the UTDM as shown in Figure 2.1. On the west of UTDM, there is the Free State Province and the country, Lesotho.

![Figure 2.1: Map of KwaZulu-Natal Province](www.uthukeladm.co.za)

The size of UTDM is approximately 11500km² (IDP, 2008). It (Figure 2.1) is located at the western boundary of KZN (IDP, 2003). It is predominately rural, with three of the five local
municipalities, namely Okhahlamba, Indaka and Imbabazane, which are rural-based. UTDM is characterised by socio-economic indicators, such as low economic base, poor infrastructure, low income, limited access to services; unemployment, shortage of skills, lack of resources, a low level of education, under-developed land and settlement patterns that make the situation difficult to plan for effective service delivery at UTDM (IDP, 2008). In spite of this, there are challenges that are associated with the attraction of investors, tourists and skilled human resources. This is due to its location away from the two major cities in South Africa, namely Durban and Johannesburg (IDP, 2003).

Private farmlands constitute the majority of the land area of the district. Most commercial farmlands in the district are located at the Emnambithi, Imbabazane, Umtshezi and Okhahlamba LMs. However, agriculture is restricted by low rainfall patterns primarily in the central areas of this District Municipality, particularly at Indaka LM (IDP, 2009). Okhahlamba LM has good agricultural potential due to a combination of high rainfalls, moderate temperatures, good soils and moderate slopes. On the other hand, agricultural potential is restricted where acidic soils, extreme temperatures and rainfall and high hail tendencies occur. Difficult topography and population pressure adversely affect productivity. In addition, erosion due to steep slopes and soil conditions are recurring problems (IDP, 2003).

The veldt carrying capacity is seasonal, being high in summer but poor during winter. Moderate agricultural potential characterises the area of UTDM, where a rainfall level is suitable for stock farming rather than crop cultivation. Moreover, the irrigation schemes have improved productivity in some areas of the Ladysmith and Umtshezi LMs that have restricted agricultural potential (Basson & Rossouw, 2003). The agricultural focus in UTDM is on extensive livestock (beef, dairy and sheep) and field crops (maize, soya beans and wheat). Some game farms and conservation areas (informal protected areas) also exist, which are linked to tourism and conservation in the district. In addition, plantations of exotics (mainly wattle and eucalyptus) can be found on private land in the south of the UTDM around Imbabazane LM (IDP, 2003).

According to the 2011-Census, there were 668 848 people living within the UTDM, which is 9.0% of the population of the KZN Province (Census, 2012). Table 2.1 provides some demographic information on how the population, in terms of gender and the overall total increased in the UTDM during 1996, 2001 and 2011, according to the census figures.
However, the 2011-Census revealed (Figure 2.2) that there are more females than males in the UTDM. The population of the UTDM is unevenly distributed. The largest population is in Emnambithi/Ladysmith Local Municipality (Census, 2012). This would imply that the increasing number of people also increases the waste generated, thus causing large problems regarding waste, if it is not managed properly.

**Table 2.1** POPULATION STATISTICS OF UTDM

<table>
<thead>
<tr>
<th>Gender</th>
<th>2011</th>
<th>2001</th>
<th>1996</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>311 183</td>
<td>302 135</td>
<td>247 700</td>
</tr>
<tr>
<td></td>
<td>(46.5%)</td>
<td>(39.0%)</td>
<td>(45.7%)</td>
</tr>
<tr>
<td>Female</td>
<td>357 664</td>
<td>355 601</td>
<td>294 759</td>
</tr>
<tr>
<td></td>
<td>(53.5%)</td>
<td>(61.0%)</td>
<td>(54.3%)</td>
</tr>
<tr>
<td>TOTAL</td>
<td>668 848</td>
<td>657 736</td>
<td>542 459</td>
</tr>
</tbody>
</table>

(Census, 2012)

**Figure 2.2** DISTRIBUTION OF POPULATION FOR LOCAL MUNICIPALITIES OF UTDM BY GENDER (Adapted from Census, 2012)
2.3 BACKGROUND TO WASTE MANAGEMENT

2.3.1 Definition of terms
Solid waste means any garbage or refuse, sludge from a wastewater treatment plant, water supply treatment plant, or any other discharge material from mining, agricultural operations and from community activities and is not wanted by anyone anymore (Naidoo, 2009).


Integrated Waste Management (IWM) is a systematic way of responding to an increasing environmental, regulatory and public concern by handling different components (paper, metals, etc.) of the waste stream in more efficient and ecologically sound ways (Ali et al., 1999).

Waste disposal refers to the dumping of unwanted material (waste or refuse) in a designated area (dumpsite), such as land filling. (Du Plessis, 2011).

Composting refers to biological decomposition of wastes consisting of organic substances of plant or animal origin under controlled conditions to a state sufficiently stable for nuisance-free storage and utilisation. The term, composting, is derived from the Latin word compositum, which means a mixture and refers to the biodegradation process (Du Plessis, 2011).

Re-use is to use an item again after it has been used (Ali et al., 1999; Naidoo, 2009).

Reduce refers to reducing or limiting the amount or toxicity of waste created (Naidoo, 2009).

Recycling means extracting valuable materials from items that might otherwise be considered as trash, and turns them into new useful products (Naidoo, 2009).

2.3.2 Municipal Solid Waste (MSW)
According to the MSW described above, waste may be semi-solid, solid or even a liquid, and is generally perceived by society as lying within the responsibilities of the municipality to collect and dispose of it. Categories of municipal solid waste include household garbage and rubbish, yard waste, commercial refuse, institutional refuse, construction and demolition debris, street cleaning and maintenance refuse, dead animals, bulky wastes, abandoned vehicles and sanitation residues.
Solid waste and its management always need special attention, because it contains a number of substances, which sometimes are detrimental to the environment (Li et al., 2007; Torbert et al., 2007). In South Africa, the management of solid waste is the responsibility of the local municipality as per the constitution and the Municipal System Act. This is accompanied by problems for municipalities situated in the rural community where there are no accredited dumpsites, no revenue collected by municipalities and no collection of waste by municipalities (Naidoo, 2009). Henceforth, it leads to poor waste management that may result in a disturbance of the surrounding environment and ecosystem (Naidoo, 2009).

The Integrated Environmental Plan (IEP, 2010) states that the local municipalities have to implement an integrated waste management plan that will enable them to deal with waste as economically and safely as possible. In the application of this plan, it should guarantee that any waste produced by the community is treated and disposed of correctly. However, if left uncontrolled, it can result in an aesthetic problem and pose serious health risks, which can be aggravated if hazardous material is present in the waste. It is therefore important that waste is collected from all sources as efficiently as possible and disposed of in controlled and licensed disposal facilities.

At the UTDM, it is necessary to understand the importance of proper disposal and the influence of landfill sites on the service provided and the community as a whole. The level of services of solid waste management depends on financial inputs and can therefore vary from one municipality to the next. However, there is a basic level of waste management services that needs to be provided to all communities, particularly households where the waste are being generated (Umhlathuze Municipality, 2005; Burnley, 2007).

2.3.3 Municipal solid waste collection and transportation

As said earlier, municipal solid waste collection and transportation are the responsibility of the local municipalities. In the UTDM, the municipalities subcontract the collection and transport of household waste to local contractors who dispose the waste at the nearest dumping sites. In the last few years, some local municipalities together with cities have contracted private sector companies with international partners to undertake solid waste removal (IDP, 2003). On the other hand, the review of the IDP (2011, 2012) states that the statistics of 2007 indicate that the majority of urban households (58%) receive the refuse
removal services from the Local Municipalities of the UThukela District, while 15.6% of households do not have refuse removal at all.

In the urban areas of the UTDM, collection rates range from 50–85% (IDP, 2009) and in the city of UTDM, which is Ladysmith, an average of 68% of the generated municipal waste is collected. This collection efficiency varies from 0% in the rural communities described as low-income areas to 90% in high-income areas (IDP, 2009). In all the towns of the UThukela district, waste collected is taken to an open dumpsite where recyclable materials are separated. The level of separation varies from one dumpsite to another, depending on the number of waste pickers working in the separation process. Ladysmith LM is using the Siyazenzela Domestic Waste Management Programme, where volunteers collect waste from rural areas and are given a food parcel as incentive per kilogram (kg) of waste collected (IDP, 2012). Open burning as a means of reducing the volume of waste that is dumped (IDP, 2003) sometimes precedes this conventional method of final waste disposal.

The separation of municipal solid waste at its generation source would greatly improve the management of solid waste (IDP, 2010). Waste management is a global problem requiring a multi-disciplinary approach. A number of studies have been undertaken to try to alleviate problems emanating from waste. Although the issue of waste management has been prioritised in South Africa, the impact continues to be a major threat to the environment (Nkwachukwu et al., 2010). Olar (2003) indicated that at the national level there are several methods, which can be employed to reduce the production of waste. These include the redesign of packaging and encouraging the use of minimal disposable material necessary to achieve the desired level of safety and convenience. This implies increasing consumer awareness of waste reduction issues and the promotion of producer responsibility for post-consumer wastes (UNEP, 1996).

2.3.4 Municipal solid waste disposal and treatment method
The disposal and treatment methods refer to a variety of techniques used to transform waste into a form that is more manageable in causing environmental problems (IRG, 2005). The waste treatment method reduces the toxicity of waste thus making the waste easier to dispose of (Sewerage and Solid Waste Project Unit, 2000). The waste disposal methods used today include subjecting the waste to extremely high temperatures (incineration), dumping on land or landfilling and using biological processes to treat the waste, like composting (UNEP, 1996). The treatment and disposal options are chosen as a last resort in solid waste
management and should be taken into account (Figure 2.3). The greatest challenge in the UTDM district is poor waste management in the landfill sites (IDP, 2010). The permits are there, but permit conditions are not adhered to due to the lack of manpower and machinery, which takes long to be repaired resulting in backlog on covering and compacting, covering material, lack of required expertise, etc.

![SOLID WASTE MANAGEMENT HIERARCHY](image)

**Figure 2.3** SOLID WASTE MANAGEMENT HIERARCHY

Illegal dumping is the critical issue in the district. The LMs are struggling to overcome this situation. Some municipalities have very old waste by-laws, but there is a problem with regard to enforcement. Umtshezi-LM has introduced spot fines for offenders. The techniques and method of handling Municipal Solid Waste (MSW) are discussed below.

### 2.3.5 Recycle, reduce and re-use

Worldwide, these triple R’s methods are recommended consistently and waste reduction in both urban and rural areas is encouraged. Many environmental benefits can be derived from applying these methods (UNEP, 1996). The utmost benefits of these methods are that they prevent greenhouse gas emissions, reduce the release of pollutants (IRG, 2005), save energy, conserve resources and reduce the demand for waste treatment technology and landfill space.
Therefore, it is advisable that these methods be adopted especially in rural communities and incorporated as part of the waste management plan (Chandak, 2010).

2.3.5.1 Recycling

Recycling initiatives vary from municipality to municipality since some municipalities are embarking on awareness programmes of waste management. In some areas of the KZN Province, recycling occurs informally at landfills, uncontrolled dumps and on streets. Waste pickers often collect materials for re-use or sale without any organisation, supervision, or regulation. Although waste pickers can be very effective to reduce the amount of plastic, glass, metal and paper, ultimately requiring disposal, pursuing these activities can be harmful to workers’ health. Nevertheless, incorporating waste pickers into organised or formal recycling programmes can improve the quality of their working conditions and the local environment (Mohammed, 2009; Rampedi, 2010).

The local municipality should encourage the separation of waste materials at the household level, as this will prevent any valuable and re-usable materials from being discarded. Following the in-home retention of valuable material, waste-pickers currently remove most valuable materials before garbage enters the waste stream or dumpsite, especially in the lower- and middle-income areas of many municipalities (Mohammed, 2009). In these cases, there is little need for additional encouragement of recycling. As the recycling of materials is an economically viable undertaking, small enterprises have and will continue to spring up whenever there is an opportunity. In fact, the theft of source-separated recyclable materials has been documented in many pilot schemes in both developed and developing nations (UNEP, 1996). Municipalities should not only recognise the trade in recyclables, they should embrace it.

Some improvement in these traditional systems is clearly desirable. First and foremost are the health concerns of the workers. Waste pickers are highly susceptible to disease and it has been proposed to provide low-cost or free protective gear, such as gloves, boots and clothing to prevent contact injuries and reduce pathogens. Little is being done to develop recycling in the UTDM. However, some LMs have and support the recycling projects of the community. For example, Imbabazane LM has assisted the Sizakancane Recycling Project from Ntabamhluphe area by providing personal protective equipment (PPE), Tractor Loader Backhoe (TLB) and transport whenever the need arises. Ladysmith and Umtshezi LMs are working with privately owned recyclers stationed at landfill sites (IDP, 2011).
2.3.5.2 Reduce and re-use

Waste reduction and re-use eliminate the production of waste at the source of usual generation and reduce the demands for large-scale treatment and disposal facilities (IRG 2005; Chandak, 2010). Methods of waste reduction include (UNEP, 1996):

- Manufacturing products with less packaging;
- Encouraging customers to bring their own re-usable bags for packaging;
- Encouraging the public to choose re-usable products, such as cloth napkins and re-usable plastic and glass containers;
- Promoting backyard composting; and
- Sharing and donating any unwanted items rather than discarding them.

All the methods of waste prevention mentioned, as part of the waste management strategy in a local municipality, require public participation. To get the public onboard, training and educational programmes need to be undertaken to educate the public about their role in the process. Facilitating this awareness should be the responsibility of local municipalities (UNEP, 1996; ENVIROS, 2004).

2.3.6 Composting

Composting is the disposal practice that involves bio-degradation of solid waste through bacterial action into humus-like material (Martin, 2011). This practice appears to be a desirable solution of environmentalists, as it results in making waste a usable product, like soil conditioners and fertilizers (Renkow & Rubin, 1998).

The nutrient content of compost is quite different from manure and other feedstock waste that go into the mix (Pap, nd). As water evaporates during the process, the carbon breaks down into carbon dioxide and phosphorous, while most of the other nutrients become more concentrated. Some nitrogen is lost during composting and some is converted from readily available forms (nitrates and ammonia) to more stable organic forms that are slowly released to crops.
Table 2.2  ADVANTAGES AND DISADVANTAGES OF COMPOSTING  
(Pap, nd:45)

<table>
<thead>
<tr>
<th>Advantages of composting</th>
<th>Disadvantages of composting</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Reduces/eliminates pathogens</td>
<td>• Pathogen control requires high temperatures and good aeration</td>
</tr>
<tr>
<td>• Reduces volume and moisture</td>
<td>• Often requires additional bulking material (carbon)</td>
</tr>
<tr>
<td>content</td>
<td>• Long processing time</td>
</tr>
<tr>
<td>• Reduces viable weed seeds</td>
<td>• Poorly run processes achieve very little</td>
</tr>
<tr>
<td>• Reduces insect larvae (fly</td>
<td>• Land required for composting and storage areas</td>
</tr>
<tr>
<td>problems)</td>
<td>• May require large investment</td>
</tr>
<tr>
<td>• Reduces odour</td>
<td></td>
</tr>
<tr>
<td>• Stabilises organic components and nutrients</td>
<td></td>
</tr>
</tbody>
</table>

The nutrient value of compost can be highly variable depending on the materials being composted and the composting system applied. Table 2.2 depicts the advantages and disadvantages of composting (Pap, nd).

There are many different methods and types of equipment and structures suitable for composting. These include (Martin, 2011):

- Windrow/pile composting – active aeration;
- Windrow/pile composting – turning;
- Windrow/pile composting – passive aeration (PAWS);
- Windrow/pile composting – static pile; and
- Vermi-composting.

Success with any of the above composting systems requires management skills and these will improve with experience. Compost managers should tour other similar facilities and compare notes with others to learn from their mistakes. If possible, start small and progressively expand as needed (Martin, 2011).

To make good compost starts with a good technique and an ability to monitor the compost and respond to changes as they occur. Keeping record of the feedstock materials being composted is very crucial. Records should also include the date the compost was turned and the condition of the compost at that time. Temperatures also need to be monitored regularly. Some standard operating procedures require daily temperature recording during the active
phase, to ensure that the required temperatures have been achieved (Martin, 2011). Notes on
the moisture condition and any odours should be made. Foul odours may indicate anaerobic
conditions or lack of oxygen. Ammonia smells may indicate high nitrogen content (C:N imbalance) and a need for more carbon material (Bandara & Hettiaratchi, 2010).

2.3.7 Incineration
Incineration, as one of the options of waste reduction and disposal, is a method that has
become extremely attractive and is a public concern. Incineration is an inappropriate
technology for most low-income countries (UNEP, 1996). In addition, a high financial start-
up and operational capital are required to implement incineration facilities, which then
become a major barrier to successful adoption in developing countries (UNEP, 1996). The
additional level of infrastructure and planning required to implement such a scheme is most
likely well beyond the realm of possibility in most developing nations. Arguments for the
adoption of incineration projects should not rely on potential energy generation. The high
costs and environmental problems have led to incinerators being shut down in many countries
and cities, among them Mexico City, Sao Paolo and New Delhi (UNEP, 1996). At present,
incineration seems to be a promising option for some countries based on financial and practical considerations.

Incineration is the combustion of waste in the presence of oxygen (Chandak, 2010). After
incineration, the wastes are converted to carbon dioxide, water vapour and ash. This method
may be used as a means of recovering energy that could be used in heating or the supply of
electricity (ENVIROS, 2004). Advantages of incineration technologies are reducing the
volume of the waste, rendering it harmless, reducing transportation costs and reducing the
production of the greenhouse gas, methane (Mohammadreza et al., 2010). The UTDM has
never implemented incineration.

2.3.8 Open burning
Open burning is the burning of unwanted materials in a manner that causes smoke and other
emissions to be released directly into the air without passing through a chimney (ENVIROS,
2004).
Open burning is most frequently practised in rural areas where household waste is not collected due to the financial burden (IDP, 2009). People use this method to reduce the volume of refuse received at the dump (Figure 2.4) and therefore, extend the life of their dumpsite (Sewerage and Solid Waste Project Unit, 2000).

According to Mohammadreza et al. (2010:57), open burning has the following negative impacts on both human health and the environment:

- “It releases many pollutants into the atmosphere, which include dioxins, particulate matter, polycyclic aromatic compounds, volatile organic compounds, carbon monoxide, hexachlorobenzene and ash. All of these chemicals pose serious risks to human health. The dioxins are capable of producing a multitude of health problems.
- Open burning has an adverse effect on human reproduction, development and disrupts hormonal systems or even causes cancer. These chemicals are considered as carcinogenic.
- Nitrogen oxides released during burning contribute to acid rain, ozone depletion, smog and global warming.
- The particulate matter creates smoke and haze, which contribute to air pollution.”

2.3.9 Landfills

Landfills are designed to greatly reduce or eliminate the risks that waste disposal may pose to public health and environmental quality (UNEP, 1996; Mohammadreza et al., 2010).
On the engineered landfill, the landfill wastes are usually placed in areas where land features act as natural buffers between the landfill and the environment. The area may be comprised of clay soil, which is fairly impermeable due to its tightly packed particles and may be characterised by an absence of surface water bodies, thus preventing the threat of water contamination (Chandak, 2010).

The bottom of the scientific landfill is lined with plastic to keep the liquid waste, known as leachate, from escaping into the soil. The modern landfills (Figure 2.5), such as sanitary landfill and bioreactor landfill are the least risk to the environment and health. However, the cost of establishing these landfills are high when compared to the other land disposal methods (UNEP, 1996; IRG, 2005).

The UThukela District Municipality had many small illegally operating landfill sites, which have been closed during recent years (IDP, 2012). Currently the UTDM is only operating one municipal landfill site, namely Acaciaville (Figure 2.6). The Ladysmith Local Municipality (ELM) is completing the site selection phase for establishing a new licensed landfill site. Nevertheless, once a new site has been selected, licensed and become operational, the Acaciaville landfill will be closed and rehabilitated in accordance with DWAF Minimum Requirements (IDP, 2012). In addition to the one existing municipal run landfill within the municipality, there is also one privately owned and operating landfill, which receives mostly
industrial waste from surrounding factories called Pieters Landfill site, but it does not cater for municipal waste.

![Existing Municipal Landfill Site in Acacia Ville](www.uthukeladm.co.za)

**Figure 2.6** EXISTING MUNICIPAL LANDFILL SITE IN ACACIAVILLE (www.uthukeladm.co.za)

### 2.4 POLICIES AND LEGISLATION REGARDING WASTE

All policies and laws, including environmental waste management planning, must comply with the Constitution of South Africa, which states that all people have the right to an environment that is not detrimental to human health. It also imposes a duty on the State to propagate legislation and to implement policies to ensure that this right is upheld. All organs of the State or administration in the national, provincial or local spheres of government have similar obligations. The principles of co-governance are also set out in the Constitution. According to the Constitution, the responsibility for waste management functions is delegated to the lowest possible spheres of government (DEAT, 2007; ENVITECH, 2010).
In KZN, according to the principle above, local government is assigned the responsibility for refuse removal, landfill sites and solid waste treatment and disposal. Whereas, provincial government has the exclusive responsibility to ensure that local government performs these functions effectively. In addition to the Constitution, a number of government policies and statutes are relevant to waste management at the local government level (Kohlscheen, 2003; ENVITECH, 2010; IEP, 2010) including, but not limited to the following:

- National Waste Management Strategy of 2010;
- National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008);
- Local Government Transition Act, 1993 (Act No. 209 of 1993);
- Municipal Structures Act, 1998 (Act No. 117 of 1998);
- Municipal Systems Act, 2000 (Act No. 32 of 2000);
- National Environment Management: Air Quality Act, 2004 (Act No. 39 of 2004);
- National Water Act, 1998 (Act No. 36 of 1998);
- National Health Act, 2003 (Act No. 61 of 2003);
- Minimum requirements for waste disposal by landfill, 2nd ed., 1998;
- Minimum requirements for water monitoring at waste management facilities, 2nd ed., 1998;
- Relevant provincial legislation, including KwaZulu-Natal Planning & Development Act 1998 (Act 5 of 1998);
- Local government by-laws and legislation on waste management, including Local Government Ordinance and Bylaws and Municipal Integrated Development Plan (IDP).

2.5 NATIONAL WASTE MANAGEMENT STRATEGY AND ACTION PLANS

The intention of National Waste Management Strategy (NWMS) is to reduce the generation of waste and the environmental impact of all forms of waste. It aims to ensure that the health of the people, the socio-economic development of South Africa and the quality of its
environmental resources are no longer adversely affected by uncontrolled and uncoordinated waste management (Rajpal, 2002).

The UTDM has identified a number of priority strategic initiatives, which were then categorised into short-term, medium-term and long-term initiatives. However, UTDM adopted action plans for the short-term initiatives, which target integrated waste management planning, a waste information system, waste minimisation and recycling, general waste collection, waste treatment and disposal (IDP, 2012).

2.6 STATUS OF WASTE AT UTHUKELA DISTRICT MUNICIPALITY (UTDM)

The Census (2012) indicated that the population of UTDM is steadily increasing, as highlighted below. These reveal that waste generation may accelerate because of population growth being proportionate to waste generation (IEP, 2010). Over and above this, waste generation requires special attention because of its impact on the environment. However, the relevant mechanisms of dealing with waste per se (disposal site) in the UTDM are limited, and some are not complying with the norms and standard for disposal as indicated in Table 2.3.

Section 2.2 described that the UTDM is comprised of five LMs. Table 2.3 summarises all legal and illegal dumpsites available in the UTDM. Out of the five LMs, DWAF has accredited a disposal site for only two municipalities. Ithala Ezakheni Industrial Estate is the only privately registered waste disposal site in the district. Security (fencing and access to sites) and general management (covering waste, wind scatter and tip pickers) at waste disposal sites appear to be an issue that needs to be attended to at almost all waste disposal sites of UTDM. DWAF (1998) stipulated that the method of disposal of waste by means of dongas, needs reassessment. This stipulation is applicable to the Ladysmith waste disposal site.
Table 2.3 EXISTING LOCAL FACILITIES AT UTHUKELA DISTRICT MUNICIPALITY (Adapted from: IDP, 2012:32)

<table>
<thead>
<tr>
<th>Local Municipality (LM)</th>
<th>DWAF permit status</th>
<th>Monthly waste disposed</th>
<th>Description of refuse</th>
<th>Expected life span</th>
<th>Prioritised in IDP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emnambithi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Ladysmith disposal site</td>
<td>Not permitted</td>
<td>2000 Tons</td>
<td>Domestic</td>
<td>Unknown</td>
<td>YES</td>
</tr>
<tr>
<td>2. Ithala-ekhakeni industrial estate</td>
<td>Permitted (GSB)</td>
<td>525 Tons</td>
<td>Domestic</td>
<td>9 years</td>
<td></td>
</tr>
<tr>
<td>Indaka</td>
<td>Not permitted</td>
<td>Unknown</td>
<td>Domestic</td>
<td>Unknown</td>
<td>No</td>
</tr>
<tr>
<td>Ekukeni disposal site</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Umtshezi</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Wembezi disposal site</td>
<td>Not permitted</td>
<td>24 Tons</td>
<td>Domestic</td>
<td>Unknown</td>
<td>YES</td>
</tr>
<tr>
<td>2. KwaNobamba (weenen) disposal site</td>
<td>Not permitted</td>
<td>Unknown</td>
<td>Domestic</td>
<td>Unknown</td>
<td></td>
</tr>
<tr>
<td>3. Escourt disposal site</td>
<td>Permitted</td>
<td>Unknown</td>
<td>Domestic &amp; garden</td>
<td>Unknown</td>
<td></td>
</tr>
<tr>
<td>Okhahlamba</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Emmause transfer site</td>
<td>Not permitted</td>
<td>72 Tons</td>
<td>Domestic</td>
<td>Unknown</td>
<td>YES</td>
</tr>
<tr>
<td>2. Van Reenen (total) disposal site</td>
<td>Not permitted</td>
<td>1 Ton</td>
<td>Domestic</td>
<td>5 years</td>
<td></td>
</tr>
<tr>
<td>3. Van Reenen disposal site</td>
<td>Not permitted</td>
<td>Unknown</td>
<td>Unknown</td>
<td>5 years</td>
<td></td>
</tr>
<tr>
<td>Imbabazane</td>
<td>No municipal site</td>
<td>No municipal site</td>
<td>No municipal site</td>
<td>No municipal site</td>
<td></td>
</tr>
</tbody>
</table>

Gabela and Knight (2010) suggested that the disposal of waste should be done in time so that there is no possibility of ground or surface water contamination during the rainy season. Related to this, a waste disposal site is located in close proximity to a water body (Ekuveni waste disposal site at Indaka LM). It is not clear whether the water body is a permanent or seasonal feature, nevertheless, waste appears to be dumped on the shores of this water body. This may have implications for water quality in the area.

Wembezi waste disposal site at Umtshezi LM is situated in close proximity to an expanding community (IDP, 2012). This has been reported to be an illegal site that is being used for waste disposal by the local community (Rajpal, 2002). Apart from the closeness, the
Wembezi site is not fenced, subsequently, animals often graze and children can be seen playing in the waste disposal site. At Umtshezi LM, most of solid waste generated is disposed of at the Escourt waste disposal site. Here again, the lack of security (fencing) at KwaNobamba waste disposal site has lead to animals and people picking from the waste disposal site. The Indaka and Okhahlamba LMs have illegal dumpsites (IDP, 2012). These sites are not permitted by DEA.

As noted in Table 2.3, Imbabazane LM has been identified as not having a waste disposal site, thus they need to prioritise in terms of a waste disposal site (IDP, 2012). However, this LM currently has no municipal sites and they have indicated that it is a priority in their IDP. Hence, in the meantime, the waste problem at Imbabazane LM is addressed by open burning.

2.7 EFFECT OF SOLID WASTE DISPOSAL ON THE ENVIRONMENT

According to Adefemi and Awokunmi (2009), solid waste has negative effects on the environment. These effects are discussed below.

2.7.1 Effect of municipal solid waste disposal practices on plant growth

Burnt ash of municipal solid waste (MSW) contains a variety of elements, such as boron, arsenic, copper, cadmium, lead, zinc, nickel, mercury, etc (Adefemi & Awokunmi, 2009). Boron is a water-soluble mineral and is washed away from the soil by continuous leaching (Adefemi & Awokunmi, 2009). Equally, cadmium, lead and mercury are also harmful to plants even at low concentrations. Mercury present in waste disposal suppresses mushroom cultivation. Elements like arsenic, copper, chromium, nickel and zinc are present in very low concentrations. The plants also take up these metals from the soil (Adefemi & Awokunmi, 2009).

2.7.2 Effect of waste on soil organisms

The disposal of solid waste to the open land increases the amount of toxicity in the soil. Soil organisms as the important substance in biogeochemical cycles to promote plant growth; are contaminated with this toxic soil and goes through their system, which in turn increases the amount of cadmium or nickel in these organisms (Adefemi & Awokunmi, 2009). This does not result in a severe threat to soil organisms only, but it also results in the death of these organisms. The death of soil organisms drastically affects the food web. Apart from soil organisms, this is also harmful to animals and children who have direct consumption of this
contaminated soil. This can cause reproductive and developmental problems and can also damage the immune system and interfere with hormones causing cancer. In fact, contaminated toxic soil consists of a group of dangerous chemicals (Gautam et al., 2011).

2.8 COMPOSITION OF ASH OF BURNT WASTE

Tapong (2002), Kamara (2006) and Nkala (2012) suggested that the lack of waste disposal facilities and logistics for household solid waste collection from rural communities, leads people to use a variety of practices for waste treatment and management which then yield waste ashes as a residue. These practices include open burning of household solid waste. Consequently, this ash in most areas, particularly rural areas, is normally disposed of into the garden or veldt, thinking that it may supplement plant growth (Tucker et al., 2001). The management of solid waste ash in rural communities is disregarded, because it will no longer emit bad odour and the volume of waste would be reduced (Nkala, 2012). Disposal of waste ash in the garden or veldt with the intention of supporting plant growth actually has an adverse effect on plant growth due to its composition varying from toxic to non-toxic substances (Serafimova et al., 2011; Dia, 2012). In this study, waste ash is categorised according to its composition, where in some cases it is composed of wood ash and some plastic ash depending on the burnt material.

Wood ash is a product of burnt wood used for cooking in some places (Serafimova et al., 2011). Wood ash contains calcium carbonates (CaCO₃) and as a result is very alkaline with the pH ranging from 10-12 (Mohammed, 2009). Throwing the wood ash in the soil or in the garden increases the alkalinity of the soil, and this creates a harmful environment for plant growth, since numerous species of plant prefer a slightly acidic environment to absorb nutrients from the soil (Dia, 2012).

The increase in soil alkalinity makes necessary minerals, such as phosphorus, iron, boron, manganese, copper, zinc and potassium to become chemically bound in the soil (Mohammed, 2009). As a result, these minerals become unavailable for plant use. In time, due to this change in the soil chemistry, plants will exhibit mineral deficiencies by producing abnormal leaves, stems and flowers (Tsutomu et al., 1976). A common symptom of plants growing in alkaline soil is interveinal chlorosis (yellowing of normal green tissue).
According Serafimova et al. (2011), wood ash increases salinity in the soil when it is disposed in the land (soil). Seedlings are very sensitive to salty soil, which stunts their growth and their foliage turns yellow. Excess salts can also cause medium to fine soils to lose their aggregated structure, becoming impervious to air and water (Mohammed, 2009).

2.9 PLANTS COMMON IN THE AREA: MAIZE

Maize is one of the commonly used indigenous plants in the UTDM. In the rural areas of the UTDM, almost all families plant maize as staple food in their gardens. Communities plant maize for various purposes, like some for business and some for food stock (IRG, 2005). Maize is the experimental plant in this study, so some literature background was deemed necessary.

2.9.1 Background of maize

Maize (Zea Mays) is known in many English-speaking countries as corn or mealie (FAO, 2009). Table 2.4 designates the scientific classification of maize. The term ‘maize’ is derived from the Spanish form of the indigenous Taíno word for the plant.

The term 'maize' is also known by other names around the world (Piperno, 2009), for example it was used in the United Kingdom and Ireland, where it is now called "sweet corn", a common crop known to people there (FAO, 2009). Corn was originally the English term for any cereal crop. In North America, its meaning has been restricted since the 19th Century to maize, as it was a shortened form of 'Indian corn' (Gautam et al., 2011). The term 'Indian corn' now refers specifically to multi-coloured 'field corn' (flint corn) cultivars (Gautam et al., 2011).

In scientific and formal usage, 'maize' is normally used in a global context. In the UK, Australia and other English-speaking countries, the word 'corn' is often used in culinary contexts, particularly in naming products such as popcorn, corn flakes and baby corn. 'Maize' is used in agricultural and scientific references (FAO, 2009). In Southern Africa, maize is commonly referred to as mielie or mealie, from the Portuguese milho (Smith et al., 1997).

Maize (Zea Mays L.) is the most important grain crop in South Africa (Du Plessis, 2003) and is a relatively easy crop to grow throughout the country in diverse environments (ARC, 1998). It is also less prone to diseases and is fairly drought resistant (ARC, 1998). Successful maize production depends on the correct application of production inputs that will sustain the
environment, as well as agricultural production. These inputs are, *inter alia*, adapted cultivars, plant population, soil tillage, fertilization, weed, insect and disease control, harvesting, marketing and financial resources (Du Plessis, 2003).

**Table 2.4  CLASSIFICATION OF MAIZE**

<table>
<thead>
<tr>
<th>Kingdom</th>
<th>Plantae</th>
</tr>
</thead>
<tbody>
<tr>
<td>(unranked)</td>
<td>Commelinids</td>
</tr>
<tr>
<td>Order</td>
<td>Poales</td>
</tr>
<tr>
<td>Family</td>
<td>Poaceae</td>
</tr>
<tr>
<td>Subfamily</td>
<td>Panicoideae</td>
</tr>
<tr>
<td>Tribe</td>
<td>Andropogoneae</td>
</tr>
<tr>
<td>Genus</td>
<td>Zea</td>
</tr>
<tr>
<td>Species</td>
<td><em>Z. Mays</em></td>
</tr>
<tr>
<td>Binomial name</td>
<td><em>Zea Mays</em></td>
</tr>
</tbody>
</table>

Furthermore, most people regard maize as a breakfast cereal. However, in a processed form it is also fuel (ethanol) and starch. Starch in turn involves enzymatic conversion into products, such as sorbitol, dextrine, sorbic and lactic acid, and appears in household items, such as beer, ice cream, syrup, shoe polish, glue, fireworks, ink, batteries, mustard, cosmetics, aspirin and paint. Approximately 8 million tons of maize grain is produced annually in South Africa on approximately 3.1 million hectare of land (Du Plessis, 2003). The production of white maize for human food consumption needs 450mm to 600mm of water per season, which is mainly acquired from the moisture reserves in the soil. About 15kg of grain is produced for each millimetre of water consumed. At maturity, each plant would have consumed 250 litres of water (Du Plessis, 2003).
2.9.2 Morphology, growth and development

2.9.2.1 Root system
The plant has a profusely branched, fine root system. Under optimal conditions, the total root length, excluding the root hairs, can reach 1500m. If root growth is not restricted, the root system of a mature plant extends approximately 1.5m laterally and downwards to approximately 2.0m or even deeper. The permanent root system has adventitious and prop roots. Adventitious roots develop in a crown of roots from nodes below the soil surface. Normally four to six adventitious roots are formed per band. After tasselling, prop roots develop into bands from the first two to three aerial nodes (Du Plessis, 2003). These roots are comparatively thick, pigmented and covered with a waxy substance. Prop roots have the dual function of providing support to the plant and taking up nutrients. Numerous root hairs occur on young plants. Root hairs increase the root surface area that is exposed to the soil and play an important role in the absorption of water and nutrients (Piperno, 2009).

2.9.2.2 Leaves
There are 8 to 20 leaves that may be formed in a maize plant and are arranged spirally on the stem. They occur alternately in two opposite rows on the stem. The maize leaf is a typical grass leaf and consists of a sheath, ligules, auricles and a blade. The leaf blade is long, narrow and undulating, tapers towards the tip and is glabrous to hairy (Du Plessis, 2003). A prominent mid-rib along its entire length supports the leaf. Stomata occur in rows along the entire leaf surface. More stomata occur on the underside of the leaf than on the upper surface. On the upper surface, motor cells are present. These large, wedge-shaped cells occur in rows, parallel to and between the rows of stomata (Piperno, 2009). During moist conditions, these cells rapidly absorb water, become turgid and unfold the leaf. During warm, dry weather, the cells quickly lose their turgor with the result that leaves curl inwards exposing a smaller leaf surface to evaporation (Du Plessis, 2003).

2.9.2.3 Stem
The maize stem varies in height from less than 0.6m in some genotypes to more than 5.0m (in extreme cases) in others. The stem is cylindrical, solid and is divided clearly into nodes and internodes. It may have 8 to 21 internodes. The internodes directly below the first four leaves do not lengthen, whereas those below the sixth, seventh and eighth leaves lengthen to approximately 25, 50 and 90mm respectively. Tillers may develop from nodes below the soil surface. The lateral shoot bearing the main ear develops more or less from the bud on the
eighth node above the soil surface. The five or six buds directly below the bud give rise to rudimentary lateral shoots of which one or two develop to produce ears (Du Plessis, 2003).

2.9.2.4 Inflorescence
Male and female flowers are borne on the same plant as separate inflorescences. Male flowers are borne in the tassel and female flowers on the ear (Du Plessis, 2003).

2.9.2.5 Maize ear
The maize ear (the female inflorescence) terminates one or more lateral branches, usually halfway up the stem. Bracts enclose the ear. The silk of the flowers at the bottom appear first, and thereafter those on the upper part of the ear appear. It remains receptive to pollen for approximately three weeks, but after the tenth day receptivity decreases (Du Plessis, 2003; Piperno, 2009).

2.9.2.6 Growth and development
Maize growth stages are numbered from zero to 10. Growth stage 0 lasts from the planting of the seed until the seedling is just visible above the soil surface. Growth stage 10 is reached when the plant is biologically mature (Du Plessis, 2003).

2.10 CONCLUSION
This chapter discussed the status of solid waste disposal practices of UThukela district municipality (UTDM). Solid waste generation in South Africa turns out to be higher than current levels of waste processing. Local municipalities show a strong commitment to solid waste disposal facilities in their IDPs, even if there is still a need for institutional strengthening so that a strong implementation capacity is enhanced. There is also a need for asserting a greater effort to improve a system of waste disposal and management in rural areas, because it seems to be biased in favour of urban areas.

Studies indicate that production of waste ash as the by-product of solid waste disposal practices is in excess in rural areas and the composition of this waste ash varies according to the burnt waste. The issue is on managing or controlling ash, which is disregarded in the households. The waste ash is composed of different properties, which include highly sensitive pH and chemicals that have a significantly adverse effect on the plant growth and may influence the richness of the soil. Studies have revealed that a number of chemicals remain active after open burning practices and certain chemicals will remain active on waste ash,
which then poses a severe threat to plant growth. Open burning practices reduce the volume and odour of waste, thus the substance composition remains as it is (Serafimova et al., 2011; Dia et al., 2012). Consequently, the present study will evaluate the effect of waste ash, in particular, on plant growth, soil richness and soil properties. The type of plant used in the study is maize.
3.1 INTRODUCTION

Theoretical perspectives of household practices regarding solid waste disposal and the various methods that the rural community practises to manage solid waste, were discussed in the previous chapter. The concepts of the waste management in the study area and the definitions of terms were clarified and the background of the study area was explained.

The waste residues used in the fields have a large influence on maize, the most common crop planted widely in this area of the KwaZulu-Natal Province, Republic of South Africa (RSA). In this study, the impact of waste ash on plant growth and on the environment regarding Solid Waste Disposal Practices (SWDP) was evaluated. Methods were chosen to achieve the research objectives focussed on the influence of waste ash, as the by-product of SWDP, on plant growth. Responsible environmental management of waste ash in rural areas are disregarded by residents as described in Chapter 2 (section 2.7), and for this reason waste ash has been overlooked as having a detrimental effect on the surroundings.

However, the main objective of this study is to evaluate the environmental impact of waste ash, especially on a common plant in an area, maize. To achieve this goal, several methods were applied. This study used mostly rudimentary source material, of which some had been collected from families as a waste with the intention of re-using.

This chapter provides an overview of the research procedures, how data was gathered, the material used and the steps followed in attaining the objectives of the study. Environmental impacts of solid waste disposal practices were determined by evaluating plant growth exposed to different types of waste residues. As the crop used was Maize, the maize plants were planted using planting pots. This planting system was used for ethical reasons (not to contaminate the study site in the event that material used containing toxic substances). ‘Re-use’, as the highly recommended way of minimising waste, was part of the project, where containers for planting were collected then used as the planting pot. Figure 3.1 is a summary
of the structure and design of this study, where the field and laboratory experiments are presented schematically.

![MATERIAL COLLECTION Diagram]

**Figure 3.1 SCHEMATIC REPRESENTATION OF METHODOLOGY**

### 3.2 PERMISSION

The Ethics Committee of UNISA, with the requirement that the researcher should always practise and maintain safety measures, as well as adhere to safety and health practices, granted the ethical clearance of this study. Permission for running the experiments on the site of UThukela District Municipality (UTDM) was granted by the UTDM head office under the Department of Health and Environment (Appendix A). The tribal authority council, through His Excellency Inkosi (Chief) Menzi Hlongwane granted permission (Appendix D) to do the
research in the rural areas of UTDM. Some rural farmers assisted the researcher by making available certain garden tools required for the experiment.

3.3 COLLECTION OF MATERIAL

3.3.1 Soil sampling

Seven soil cores were taken, according to Mason (1992), to a depth of 10-15 cm at 3 m intervals on an area (sampling site) measuring 5 m x 10 m (50 m$^2$). Soil was sampled using a stainless steel soil-sampling probe (borrowed from local farmers). The probe was thoroughly cleaned before use to prevent the possibility of cross contamination.

A zigzag pattern was followed during sampling (Figure 3.2) to sample sequentially in a simple random pattern across the field to collect soil cores of equal size. The soil sampled for this experiment was in one area that had a flat surface, to make sure that the area has similar soil, fertility history and soil characteristics (colour, slope, texture, drainage). The samples had to reflect the fertility of the soil accurately so that the analysis, interpretations and recommendations reflect the nutrient status of the entire field correctly.

![Zigzag Pattern of Soil Sampling](image)

**Figure 3.2** ZIGZAG PATTERN OF SOIL SAMPLING

Soil cores collected for each sampling depth were then mixed according to the method suggested by Kramers et al. (2003). Individual soil cores were mixed thoroughly in a clean soil sample bag. Afterwards, each sample was dried in the clean room, which is protected from direct sunlight, wind and dust (Mason, 1992). This was done in order to obtain accurate fertility recommendations from the laboratory.

The dried soil was then packed in the soil sample bag, and was sent to Cedara College of Agriculture, KZN Department of Agriculture and Environment, where the required test analyses were done to evaluate the fertility composition of the samples. The standard
operating procedure for soil sampling of the Cedara College of Agriculture was followed. A technician from Cedara conducted the test analysis.

3.3.2 Waste collection

Household solid wastes were collected from the UTDM. The ten families, who were selected on the grounds of their willingness to participate, were provided with four waste bags per family. The families were asked to separate waste into renewable and non-renewable wastes (Kamara, 2006; Mazinyo, 2009). An explanation and demonstration of how to categorise wastes as renewable or non-renewable were provided, while personal protective equipment (PPE) was worn. This was done with each family participating. Families were asked not to burn this waste, as was their usual disposal practice, thus waste reduction was encouraged. The bags were labelled on the day of issue as renewable and non-renewable material respectively. The families were visited daily to monitor whether they were able to categorise waste in the bags. Waste bags were collected on Day 3 at all households. These collections were repeated three times. Safety measures were observed continuously. The quantities and type of waste collected were recorded.

Re-usable material were properly and tightly closed with cable cord and transported from homesteads to the study site. This is where the rudimentary materials necessary for the purpose of the research were separated and collected. Moreover, the researcher re-used it again in the study. PPE, such as a mask and heavy gloves, were worn. Old dishes, bucket, utensils, and sealed plastic bottles collected from the above re-usable material were used in this project. Old spacious dishes and buckets were available to use as planting pots. Sealed plastic bottles were used to collect waste ashes. Plastic bottles were cleaned with 70% alcohol to eliminate all pathogenic substances, which can be contagious and lead to false results (Ike-Izundu, 2007).

Waste ash, as the product of the normal waste burning practices in the community, was randomly collected from the ten families. The researcher only used what is already happening in the area on a regular basis. Waste ash was collected from the site where the family normally burnt their household waste. These ashes were collected on the day of burning, once the ash had cooled down. The days of collecting waste ash were not in sequence because households did not burn waste on a specific day. They burnt once the volume of solid waste had increased in the dumping area. Wood ash was collected from homesteads that rely on
wood fire for cooking and were collected from the place where normally dumped. The collected wood ashes were placed in sealed plastic bottles.

*Plastic ash* was also collected from the informal dumping site of the Bergville community. At this dumping site, waste is categorised and separated for recycling, re-use and compost. Open burning then occurs of the remaining unused material, although burning of waste rarely took place. Plastic waste ashes were collected and placed in bottles and sealed. Part of the sample of waste ashes was sent to the accredited laboratory, Global ALS laboratory for chemical analysis. The standard operating procedure of Global ALS laboratory was followed during the chemical analysis, which was performed by a technician from Global ALS.

### 3.3.3 Apparatus and equipment

Figure 3.3 shows the prescribed fertilizer [NPK 2:3:2 (22)], and compost which were bought from a local agricultural shop.

![Fertilizer, Compost and Zea Mays Seed](image)

*Figure 3.3  FERTILIZER, COMPOST AND SEED OF ZEA MAYS*

Garden fencing and poles were bought from a local hardware store. The irrigation system and garden equipment were bought from local agricultural shop in the area. Rudimentary materials collected from waste as a way of re-use or recycle were used mostly in this research project. Figure 3.3 also shows *Zea Mays* (maize) seed material, which was obtained from
local farmers in the area of UTDM and was instrumental in this study. Fertilizer prescribed by Cedara College of Agriculture Laboratory and compost bought from agricultural shop in an area served as control in the study. *Zea Mays* seeds were the only cultivars planted in this project.

### 3.4 EXPERIMENTAL DESIGN

The study was conducted from March 2013 to February 2014. The climatic conditions at UTDM have a huge seasonal variations, thus planting experiments were done twice. The first planting took place in winter on 15 June 2013 and the second planting on 7 September 2013 when winter had lapsed. At the first planting experiment (in winter), plants were grown under greenhouse conditions to prevent frost damage in the morning and solar radiation with the air temperature regulated between approximately 15°C (night) and 27°C (day). The second planting experiments (summer) were managed in a controlled fenced garden with no greenhouse. This was because rural farmers regard September and October as planting months because temperatures are at optimum levels for plant growth.

#### 3.4.1 Preparation of garden and planting pots

Planting experiments were conducted in a controlled environment called “the garden” (Fanadzo et al., 2009) as described above. The area of the garden was 12m² (3m × 4m). The garden was thoroughly monitored and fenced, so that no hares and goats could come inside to eat the plants. The old collected dishes were thoroughly cleaned and used as the planting pots. A number of holes were opened underneath of all planting pots to prevent water logging. In preparation for these experiments, top soil (10-15cm) was dug from the study site, as was explained above, using a garden spade. Each planting pot was filled with soil to approximately three quarters full (¾). For each planting experiment, twelve planting pots were prepared and ready for use as indicated in Table 3.1. The volume of all planting pots was calculated using the following formula:

\[
V = \pi r^2 h
\]

**Equation 3.1**

Where: \( V = \) Volume; \( r = \) Radius; \( h = \) Height

Table 3.1 shows the labelling of planting pots with calculated volume of each pot. Since two pots were used for each type of additive, the pots were categorised as 'a' and 'b'. The planting pots were labelled with the calculated volume using a permanent marker. A ruler tape was used to measure the height as indicated in Figure 3.4.
### Table 3.1 PLANTING POT WITH CALCULATED VOLUME

<table>
<thead>
<tr>
<th>Additive for planting pot</th>
<th>Computed volume* (litre/dm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compost</td>
<td>Pot 1a: 25.50</td>
</tr>
<tr>
<td></td>
<td>Pot 1b: 30.30</td>
</tr>
<tr>
<td>Prescribed fertilizer</td>
<td>Pot 2a: 20.05</td>
</tr>
<tr>
<td></td>
<td>Pot 2b: 20.50</td>
</tr>
<tr>
<td>No nutrient added</td>
<td>Pot 3a: 10.50</td>
</tr>
<tr>
<td></td>
<td>Pot 3b: 15.50</td>
</tr>
<tr>
<td>Waste ash</td>
<td>Pot 4a: 20.05</td>
</tr>
<tr>
<td></td>
<td>Pot 4b: 21.50</td>
</tr>
<tr>
<td>Wood ash</td>
<td>Pot 5a: 15.50</td>
</tr>
<tr>
<td></td>
<td>Pot 5b: 20.50</td>
</tr>
<tr>
<td>Plastic ash</td>
<td>Pot 6a: 25.50</td>
</tr>
<tr>
<td></td>
<td>Pot 6b: 19.50</td>
</tr>
</tbody>
</table>

*Equation 3.1: $V = \pi r^2h$

'a' and 'b' represent the first and second planting respectively, after the nutrients were added.

---

**Figure 3.4 MEASURING VOLUME OF PLANTING POTS**

All planting pots were arranged in two lines and set up 0.2m apart from one another (Figure 3.5).
3.4.2 Application of fertilizers and ashes to planting pots

Plants depend on the nutrients in the soil to grow and flourish (Utzinger et al., 1991). However, in this study obtaining a fertile soil was one of the most central tasks. A soil fertility test was done to determine nutrient content and pH. This test was performed at Cedara College of Agriculture Laboratory, to establish a basic soil fertility level. The results obtained from Cedara College helped to establish a programme of obtaining fertile soil. The results of the soil fertility test outline the nutrients in the form of fertilizer that need to be applied to the sampled planting pot.

The following additives to the soil where used to prepare the pots: chemical fertilizer recommended by the laboratory, organic fertilizer (compost), ashes (wood ash, already burnt ash and plastic ash) and the last one no nutrients or fertilizers were added. Application of fertilizers and ashes were equal for all planting pots in terms of ratios, namely 50g: 5L or dm$^3$. The ratios of all planting pots with known volume were calculated as specified in Table 3.1, so that all planting pots receive an equal percentage of additives. The ratios of each planting pot were noted on the worksheet. Two planting pots were used for each nutrient, in other words, planting pots were duplicated for each of the nutrients.

All additives (compost, fertilizer, waste ash, wood ash and plastic ash) were sampled and weighed, using a weighing scale borrowed from the local school laboratory. All samples were weighed according to ratios calculated per planting pot. The weighed samples were then placed in separately labelled plastic bags. The fertilizers were applied on a day without much wind in the greenhouse and this was done with the use of old spoons collected (and
thoroughly cleaned) from household solid waste. Each fertilizer had a separate spoon to prevent cross-contamination.

Figure 3.6 shows how the fertilizer was applied to the planting pot. PPE were worn and adhered too according to health and safety practices. The soil and fertilizer were thoroughly mixed with the same spoon in each of the planting pots and afterwards water was irrigated to all planting pots to make additives dissolve efficiently in the soil.

![Figure 3.6 MIXING ASH AND SOIL IN PLANTING POT](image)

### 3.4.3 Planting of Zea Mays in planting pots

The maize seeds collected from the stock of rural farmers (Figure 3.3) were used to plant in the planting pot. All planting pots were watered well before planting to allow the soil to drain until it can be worked without becoming muddy (ARC, 1998; DAFF, 2002).

Four seeds were planted per planting pot to provide more variance of the results. The seeds were spaced 2cm to 5cm apart. The depth of sowing was 1cm and the seed was then covered with soil taken from the same planting pot. The crop was kept weed free according to the recommendation of Fanadzo et al. (2009) using a manual weed control method, where weed were removed by using hand hoeing and hand pulling. The seeds were all sown on the same day. The supplementary irrigation was applied equally in all planting pots after the seeds were planted.
3.4.4 Evaporation pan and irrigation method

Different plant types require different amounts of water depending on environmental conditions and this indicates that the amount of water used by a plant depends on solar radiation, temperature, wind and humidity (McMullin, 2006). Water can be lost from the soil surface and wet vegetation through a process called evapo-transpiration (Savva & Frenken, 2002). The latter is a process whereby water in liquid form is converted into water vapour and removed from the evaporating surface (Bauder, 1986). In this study, the evaporation pan was used to determine the amount of water released per day to determine the water needs of the plants.

The evaporation pan test was done on a hot (cloudless) and a cool (cloudy) day for two consecutive days, one after the other (one hot, one cold); however both days were windless days. The national forecast was used to determine the weather of the day. This test was done in summer time only in order to determine the amount of water in the warmest circumstances. Transparent open dishes with measurement markings were used as the evaporation pan (EVP). A volume of 1.5 litres of water measured with measuring cylinder was poured on the EVP on the windless day. Water was poured at 08h00 in the morning. This test lasted for a day (24 hours); however, the next reading on EVP was done on the following day at exactly the same time. The intention with this test was to determine the amount of water lost per day through evaporation. The same test was repeated on a cloudy day. The EVP was monitored every two hours for the entire day. This enabled the researcher to determine the frequency for the watering of the plants.

A handheld bottle was used as a spray system as the irrigation method in this project. The formula to determine the amount of water that has to be applied per planting pot was based on the outcome of the evaporation pan test. It was observed that on a sunny day about 80ml of water is released to the atmosphere through evaporation in 10 hours; hence the water irrigated per plant in a planting pot was 150ml. Irrigation was done twice a day between 08h00 to 08h30 in the morning and 16h30 to 17h00 in the evening. It was noted that evaporation occurs more in winter than summer, thus more water must be supplied in winter than summer. Figure 3.7 shows the researcher irrigating the plants in the planting pots. This irrigation method ensured that water is not spilled, but carefully irrigated into the planting pot only.
3.4.5 Measuring plant growth

Plant profiles were measured from the soil surface to the tip of growing leaves of fully established maize (*Zea Mays*) (Tang & Boyer, 2002; Richard, 2004). The following selected agronomic parameters were measured: plant height, stem circumference, number of leaves and colour of leaves per plant. The plant height was measured weekly (every Thursday) using a ruler. Measuring started 14 days after planting. The plant growth rate was calculated using the following equation (Mostafa & Derbala, 2013a:264).

\[
R_n = \frac{(X_n) - (X_{n-1})}{7}
\]

Equation 3.2

Where:  
\( R_n \) = growth rate in the week \( n \) (cm/day/week)  
\( n \) = number of the week from the starting of the experiment  
\( X_n \) = plant height (cm) in the week \( n \)  
\( X_{n-1} \) = plant height (cm) in the previous week of the week \( n \)  
7 = constant, number of days per week (days)

Selected agronomic parameters were measured with technical precision without harming the plants. All measurements were recorded manually on a record sheet specifically designed for this experiment.
3.5 CONCLUSION

This chapter described the materials and methodology used for data collection and analysis. Field methods included, waste collection from the households; collection of soil samples; preparation of planting area (garden) and planting pots; planting and monitoring plant growth; and designing a proper and effective irrigation system. Laboratory methods were used for the soil fertility test and analysis of chemical concentration of trace element in solid waste ash. These services were provided by and done at the Cedara College of Agriculture and at ALS Global Laboratory respectively.

In this study, the direct seed planting was done consecutively in winter and summer as the objective was to evaluate the effect of disposing ashes (of household solid waste) on plants. The outlined method of waste collection was intended to promote and improve the management of solid waste, including reduction, re-use, recycling and recovery. Moreover, since the study focussed on the rural community, the rudimentary material collected from the community waste was mostly used for the project. This was done to demonstrate that all materials could be re-used. At all times, safety and health were adhered to at all times, since waste can contain pathogenic and hazardous substances.
Chapter 4
RESULTS AND DISCUSSION

4.1 INTRODUCTION

Chapter 3 introduced the research methods and established their purpose and relevance for this study. Preparation of soils with various additives (waste ashes, compost and fertilizers for plant supplement) prior to planting was to ensure that the maize seeds planted absorb the additive added. This chapter presents the results of all the field data (types of waste collected, soil fertility testing, trace element concentration in waste ashes and plant growth) that were collected and analysed during the course of the experiments. Moreover, this chapter outlines a discussion of the results of all the experiments in this research work in accordance with the aim and objectives of this study.

4.2 SOLID WASTE COLLECTION AND DISPOSAL PRACTICES

In South Africa, the biggest waste collection problems exist in rural and informal settlements (CSIR, 2011). In certain areas of UThukela District Municipality (UTDM), road infrastructure is limiting the waste collection vehicles to reach all the households. Moreover, households in rural areas of UTDM are sparsely distributed over long distances and the available streets are often too remote and unsuitable for conventional waste collection vehicles. Deep potholes, narrow roads, steep slopes and dongas also hamper access of waste removal vehicles to these areas (CSIR, 2011). Hence, these were regarded as factors that contribute to rampant illegal dumping and subsequently, compelled rural people to acquire alternative waste disposal practices.

The type of solid waste collected for this study in the rural community of UThukela District Municipality (UTDM) varied from already burnt waste ash (3.5kg), to plastic ash (2.4kg), wood ash (8.0kg), food waste (5.5kg), and old dishes (25 units) (Table 4.1). The other waste materials were not weighed because it was not considered necessary for the study. These include, utensils, corrugated iron, broken branches of trees, batteries, used nappies, plastics, old food cans (34 units), discarded electrical material and household appliances. The solid waste materials were collected from different families as described in Chapter 3 and re-used
in the study where feasible. These materials were needed for various purposes, for example old dishes, corrugated iron and utensils were used as the planting pots. Waste ash was used as an additive (soil mix with waste ash, compost and fertilizers) to supplement plant growth. The waste materials that were not used in this study weighed 8kg and were disposed of in the permitted landfill site.

Table 4.1 TYPES AND QUANTITY OF SOLID WASTE COLLECTED FROM SELECTED UTDM FAMILIES

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Already burnt ash</td>
<td>3.5kg</td>
</tr>
<tr>
<td>Plastic ash</td>
<td>2.4kg</td>
</tr>
<tr>
<td>Wood ash</td>
<td>8.0kg</td>
</tr>
<tr>
<td>Food waste</td>
<td>5.5kg</td>
</tr>
<tr>
<td>Old dishes</td>
<td>25 units</td>
</tr>
<tr>
<td>Old tins</td>
<td>34 units</td>
</tr>
<tr>
<td>Disposable material</td>
<td>8.0kg</td>
</tr>
</tbody>
</table>

Because no waste collection service is available, the community resorts to an alternative illegal dumping and consequent burning of the dumped household solid waste. This has become the common waste disposal practice in rural areas of UTDM and it is affecting the environment in various ways, as concurred by the studies of Human (2005) and Maluleke (2014). The study conducted by PPDC (2004) revealed that South Africa is facing a lack of an integrated waste management system. This was witnessed when the waste products gathered from the study site (UTDM) were analysed. The waste products were composed of varied non-toxic to toxic components. The composition of solid waste collected from different households, as described above, included waste ash that is the by-product of solid waste disposal practices in the area. It was observed that these waste ashes consisted of various chemicals of which some are detrimental to the environment while some are needed into certain quantities. The analysis of the chemical composition of the waste ash is discussed under section 4.7.

The findings of a study conducted by Amy et al. (2003) reveal that certain household products (dish soap and glass cleaner) contain chemicals that retard plant growth. This question is addressed in the current study, which evaluated the impact of household solid waste disposal
practices (waste ash, wood ash and plastic ash) on plant growth. The municipal management of solid waste is poor and often does not exist in the certain rural areas of UTDM. Consequently, this has compelled the residents to adopt illegal solid waste disposal practices, like burning waste, with its residues (waste ashes) washed away by water or blown by the wind from the burning site to the surrounding environment. Hence, the ecosystem is vulnerable to these factors caused by the waste ash in the environment. Maize, as the common plant in this area (where this waste disposal is practised), is subjected to the effects caused by these disposal practices.

The census of 2011 revealed that the population of UTDM has increased by 9048 people since 2001, thus it can be accepted that household solid waste generation would have increased accordingly. Even though some people do not have basic salaries or stipend as the source of income, they manage to find food to eat, which subsequently would generate waste. The unavailability of landfill and disposal sites in the rural areas of UTDM influences the residents to acquire and practise different systems of disposing and controlling household solid waste. It was observed that where waste is not collected, the residents of UTDM control waste by disposing it in open areas and then burning it to reduce the quantity resulting in waste ashes being left as residues. Other methods practised by a few families are recycling, re-using and reducing. Judging by the way their waste is managed, without considering pollution; it is obvious that environmental awareness has not yet been facilitated in certain areas.

Household solid waste in rural areas is composed of hazardous, toxic and non-toxic substances (Ubani, 2012). The life span of this waste varies among the products dumped and, furthermore, some of these wastes are non-biodegradable and some are biodegradable. According to Ubani (2012), it is essential to manage non-biodegradable waste and dispose of it correctly. The accumulation of non-biodegradable waste in UTDM is too high compared to biodegradable waste, as witnessed by the volume of dumped bottles and plastics waste. On the other hand, some people use biodegradable waste to make compost, which is the alternative and environmentally appropriate route to manage such waste.

The studies of UNEP (2003) and Visvanathan and Glawe (2006) revealed that the generation of municipal solid waste differs greatly from place to place. On the other hand, its production is influenced by the standard of living, seasonal variations in climate and cultural practices. This concurs with the type of waste collected from the study site, which differed from
household to household. The rate of waste generation and its composition varied among households. This was also reported in the study of Visvanathan and Glawe (2006).

4.3 SOIL FERTILITY TESTING RESULTS

The purpose of this experiment was to establish whether the practices mentioned above have a detrimental effect on the soil, and therefore, on the potential of the soil for planting. Soil fertility analyses were done prior to planting seed in the planting pots (Table 4.2). Based on the soil test results, all planting pots received equal parts of selected additives for plant supplements (different waste ash, compost and fertilizers) in terms of the ratio 50g:5L (as was described in Chapter 3). No fungicides or insecticides of any kind were applied to the soil or foliage for the duration of the trial.

Table 4.2  SOIL FERTILITY NUTRIENTS AND LIME RECOMMENDATIONS

<table>
<thead>
<tr>
<th>Sample soil test mg/L</th>
<th>Target soil test mg/L</th>
<th>Req. P kg/ha</th>
<th>Sample soil test mg/L</th>
<th>Target soil test mg/L</th>
<th>Req. K kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>12</td>
<td>60</td>
<td>95</td>
<td>120</td>
<td>60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nitrogen</th>
<th>Lime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield target t/ha</td>
<td>Req. N kg/ha</td>
</tr>
<tr>
<td>12</td>
<td>200</td>
</tr>
</tbody>
</table>

**NOTE:** Sample soil test and sample acid saturation reflect the soil test values of the sample submitted. Required P and required K (coloured red) are the amounts of P and K required raising the soil test to the target value. Lime required (coloured red) is the amount of lime needed to decrease the soil acid saturation to the permissible acid saturation (PAS). Zinc fertilizer was not required.

The results indicate that the texture of the soil collected from the study site was silt-clay and the pH was slightly acidic with pH of 4.07 as denoted in Table 4.2 and Appendix B. The soil pH greatly influences the availability of nutrients in the soil as was also observed by Ozores-Hampton et al. (1994), Medinski et al. (2007), Ubuoh et al. (2012) and Ilay et al. (2013). It also influences the activity of micro-organisms in the soil (Medinski et al., 2007). However, the laboratory of Cedara College of Agriculture, where the soil analysis was done, recommended that the soil pH could be amended by adding lime or sulphur at least one to two months before planting and should be incorporated to a depth of 20cm. This was not done in this study.
The macro- and micro-nutrients needed by plants to grow were available in the tested soil in different quantities and included Nitrogen (N), Phosphorus (P) and Potassium (K). The exchangeable cations were also present in the different quantities tested. These were Calcium (Ca), Magnesium (Mg), Manganese (Mn), Zinc (Zn) and Copper (Cu). The available quantities of these nutrients were not enough, hence the growing plant needed a supplement for plant-uptake in the form of fertilizer. As shown in Table 4.2, the following fertilizers were suggested by the Laboratory, namely Di-Ammonium Phosphate (DAP), Mono-Ammonium Phosphate (MAP), Double Supers, 2:3:2 (22), KCl, LAN and urea. They indicated that they should be applied as bag/hectare.

The soil fertility test was performed to determine the nutrients, minerals and pH of the study site soil as indicated in Table 4.2. This revealed that certain minerals are present in large quantities, such as Cu = 11.2mg/L, Mg = 318mg/L and Mn = 21mg/L. These results concurred with the study of Basson (1997) who reported that the area of UTDM has good agricultural soil that is confirmed by the properties of the soil as shown in Table 4.2 and Appendix B. The soil is rich in the nutrients necessary for plant growth and it contains minerals, microbial activities and organic matter that improve soil structure, as well as soil moisture retention.

4.4 GERMINATION OF ZEA MAYS

The germination of seeds were monitored and recorded on a worksheet according to a predetermined schedule of irrigating twice a day, observing and recording all agronomic parameters weekly. The germination of the plants started after seven days of planting and varied up to two weeks as denoted in Table 4.3. However, the plant soil without-additives showed positive germination in summer, whilst in winter it took more than a week to germinate. Conversely, plants supplemented with additives of waste, wood and plastic ash showed poor germination in both the first and the second planting experiment and even the number of leaf sprouts varied from 1 to 2 leaves in the third week of planting. The plant growth measurements started after 14 days of planting as all plants had germinated by then. All selected agronomic parameters and the growth rate after 18 days (three weeks) of planting were measured as described in Chapter 3 and the results are presented in the Table 4.3 and shown in Figure 4.1 for the winter and summer planting respectively. The plant growth was evaluated during the two seasons (winter and summer) to determine the variation among seeds that were supplemented with waste ash.
<table>
<thead>
<tr>
<th>Additives to the soil</th>
<th>Seeds germinated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1st Planting</td>
</tr>
<tr>
<td></td>
<td>(Winter)</td>
</tr>
<tr>
<td>1. Waste ash</td>
<td>##</td>
</tr>
<tr>
<td>2. Wood ash</td>
<td>##</td>
</tr>
<tr>
<td>3. Plastic ash</td>
<td>##</td>
</tr>
<tr>
<td>4. Compost</td>
<td>#</td>
</tr>
<tr>
<td>5. Prescribed fertilizer</td>
<td>#</td>
</tr>
<tr>
<td>6. Without additives</td>
<td>##</td>
</tr>
</tbody>
</table>

# = Sprouts out after the first 7 days of planting  
## = Sprouts out after 2 weeks of planting

There are no significant differences for *Zea Mays* germination between winter and summer planting (Table 4.3), however, the plants growing in the planting pots consisting of soil only (without any additives) were mostly varied, particularly regarding plant height. The colour of the germinated plants varied from green, dark green and weak yellow. Plants with compost and prescribed fertilizer soil mixture were green from the second week of planting in both winter and summer.

![Figure 4.1 SEED GERMINATION 18 DAYS AFTER PLANTING](image)

Four seeds were planted in each planting pot. The plants did not germinate on the same day but its germination was observed to show continuous sprouting throughout the week. The germination of the seeds planted with waste ash in the soil showed variation in winter, yet some of the planted seed germinated only after 23 days of planting. In addition, the weather conditions during the course of this study were highly varied with the coldness and no rain in winter, along with moderate temperatures and the average of 60% rainfall in summer. It was
observed that these differences in the weather conditions may well have contributed to differences in seed germination, but all plants were exposed to the same weather conditions.

The germination results of the seeds in soil supplemented with waste ash, compost, prescribed fertilizer and without additives were evaluated after 18 days of planting, which is regarded as the germination period. Figures 4.2, 4.3 and 4.4 show the images of plant sprouts, which were supplemented with wood ash, waste ash and plastic ash respectively. Hence, all of these plants propagated on the same day and they were treated equally with all variables, namely the same type of soil, as well as being irrigated with equal volumes of water. In addition, Figures 4.2, 4.3 and 4.4 show the results of the first planting (winter).

Figure 4.2  GERMINATION OF SEEDS IN SOIL SUPPLEMENTED WITH WOOD ASH AFTER 18 DAYS IN WINTER
Figure 4.3  GERMINATION OF SEEDS IN SOIL SUPPLEMENTED WITH WASTE ASH AFTER 18 DAYS IN WINTER

Figure 4.4  GERMINATION OF SEEDS IN SOIL SUPPLEMENTED WITH PLASTIC ASH AFTER 18 DAYS IN WINTER
The plants depicted in Figures 4.5, 4.6 and 4.7 of the second planting (summer) grew freely when compared to those in Figures 4.2, 4.3 and 4.4. This indicates that germination of seeds in the soil with waste ash additives differed significantly when compared to those seeds in the soil with compost and fertilizer additives.

![Figure 4.5](image1.png)  GERMINATION OF SEEDS IN SOIL SUPPLEMENTED WITH COMPOST AFTER 18 DAYS IN SUMMER

![Figure 4.6](image2.png)  GERMINATION OF SEEDS IN SOIL SUPPLEMENTED WITH PRESCRIBED FERTILIZER AFTER 18 DAYS IN SUMMER
Figures 4.2 to 4.7 show a variety of germinated plants based on the different additive soil mixes in their planting pots. The 18 days after the seeds were planted was chosen as the day to assess plant germination in all planting pots, as all the seeds planted had sprouted. It was observed that some seeds planted did not germinate, revealing that some additives do not contain primary nutrients, which are essential for plant germination. Srivastava and Rao (2014) also observed this. The agronomic parameters (plant height, number of leaves and plant colour) of the plants germinated differently for the different additives. For example, Figure 4.6 (with prescribed fertilizer as additive) shows a colourful green and 2 to 3 leaves, while Figure 4.7 (without additives) shows dark green leaves indicating a loss of water (leaves are shrinking).

The seeds planted were able to sprout in all six additives, in both winter and summer, even though in other additives some planted seed were not all able to germinate as indicated in Figure 4.8. Table 4.4 presents the measurements of the agronomic parameters (plant height, stem circumference, number of leaves and colour of leaves) of the germinated plants. The results indicate that plant growth differed among the additives, as well as for winter and summer. There were significant differences in the height of plants in waste ash soil in winter (2.8cm) and waste ash soil in summer (4.3cm). No changes between the seasons were observed regarding colour and the number of leaves of the germinated plants.
Table 4.4  AGRONOMIC PARAMETERS FOR FIRST 18 DAYS OF PLANTING ACCORDING TO ADDITIVES IN SOIL (MEAN OF THE FOUR SEED PLANTED)

<table>
<thead>
<tr>
<th>Additives to soil</th>
<th>Plant height (cm)</th>
<th>Stem circumf. (cm)</th>
<th>Number of leaves</th>
<th>Colour of leaves</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WINTER</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood ash</td>
<td>3.0</td>
<td>2.0</td>
<td>2</td>
<td>Weak green</td>
</tr>
<tr>
<td>Waste ash</td>
<td>2.8</td>
<td>2.3</td>
<td>2</td>
<td>Weak green</td>
</tr>
<tr>
<td>Plastic ash</td>
<td>3.0</td>
<td>2.0</td>
<td>2</td>
<td>Weak yellow</td>
</tr>
<tr>
<td>Without additives</td>
<td>5.4</td>
<td>4.2</td>
<td>2</td>
<td>Weak green</td>
</tr>
<tr>
<td>Compost</td>
<td>10.0</td>
<td>6.5</td>
<td>3</td>
<td>Green</td>
</tr>
<tr>
<td>Prescribed fertilizer</td>
<td>11.5</td>
<td>7.0</td>
<td>3</td>
<td>Green</td>
</tr>
<tr>
<td><strong>SUMMER</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood ash</td>
<td>4.0</td>
<td>2.0</td>
<td>2</td>
<td>Weak green</td>
</tr>
<tr>
<td>Waste ash</td>
<td>4.3</td>
<td>2.0</td>
<td>2</td>
<td>Weak yellow</td>
</tr>
<tr>
<td>Plastic ash</td>
<td>3.7</td>
<td>2.0</td>
<td>2</td>
<td>Weak yellow</td>
</tr>
<tr>
<td>Without additives</td>
<td>7.8</td>
<td>5.5</td>
<td>2</td>
<td>Weak green</td>
</tr>
<tr>
<td>Compost</td>
<td>12.5</td>
<td>7.0</td>
<td>3</td>
<td>Green</td>
</tr>
<tr>
<td>Prescribed fertilizer</td>
<td>13.0</td>
<td>7.0</td>
<td>3</td>
<td>Green</td>
</tr>
</tbody>
</table>

Figure 4.8  PERCENTAGE OF SEEDS GERMINATED IN WINTER AND SUMMER

A positive significant influence of fertilizer and compost on shoot elongation was observed in the seeds planted compared to those seeds planted in the soil with waste ash as additive. This
was revealed in Figures 4.2 to 4.8. Germination percentages (Figure 4.8) present encouraging results where the soil was enhanced with compost and fertilizer compared to plants supplemented with waste ash. The effect of the waste ash, in comparison with compost and fertilizer, was evident by the slower rate of germination and less plant growth.

Srivastava and Rao (2014) mention that the rate of seed germination varies among plants and the treatment added to the soil. It was evident in this study that the germination stage, where the soil was supplemented with different waste ashes, it took 14-21 days to sprout, whereas those supplemented with fertilizer and compost, took a week (7 days) to germinate. This indicates that waste ashes additives do not contain essential nutrients that support germination.

On the other hand, the plants supplemented with waste ash varied from yellowish to green (Table 4.4) and the plant structure indicates that the soil is not nutrient-rich enough to grow effectively. The plastic ash additive (soil supplemented with plastic ash) was the only variant that took more than nine days to show signs of germination. Out of the 4 seeds planted, only 1 seed (25%) planted in the winter planting germinated and the rest did not germinate at all (Figure 4.8).

The seasons (winter and summer) did not have a significant influence on seed germination, except the plants with no additive added (plant with soil only) and the wood ash additives, which varied from 75% (3 out of 4) of the seeds planted in winter. For those seeds planted in soil with no additives, 100% germinated in the summer. In contrast, for the wood ash additive, 50% germinated in winter and 75% in summer (Figure 4.8).

Furthermore, all the plants grown in summer were green to strong green, except in the case of the plastic ash additive where the plants were pale yellow in the first week of germination. The winter-planting plants with the plastic ash additive (Figure 4.9) required special attention after they germinated, as they looked dry (loosing water) although all additives were irrigated equally, the leaves shrunk and two of the plants collapsed due to dehydration, in spite of the fact that water was excessively applied to rescue those plants.
The height of the plants differs among the additives. As indicated by Tucker (1999), Nitrogen (N), Phosphorus (P) and Potassium (K) are essential elements for plant growth. This study has also shown that some of the additives have insufficient nutrients to support seed germination and plant height. The compost and fertilizer contain the necessary elements needed by plants to germinate and grow. This was evident in the plant height, stem circumference and number of leaves of the sprouts, which performed well. When comparing plant growth of waste ash additives and compost additive, there is a vast difference as shown in Figures 4.2 to 4.5. The average plant heights for waste and plastic ash additives were 2.8cm and 3cm respectively in winter, while those with the compost and fertilizer additives were 10cm and 11.5cm respectively.

4.5 RESULTS OF EVAPORATION PAN TEST

The Evaporation Pan Test was done to determine the average amount of water lost per day for the study site. The outcome of this test helped to develop the irrigation system used in the study, particularly regarding the minimum estimated amount of water to be irrigated on a day. The test was done in different weather conditions (hot and cool/cold day) separately because the rate of evaporation is high on hot day (Phaleng, 2009). The average water release on the
hot day was 80.7ml/day, while on the cool day 30ml/day was measured (Table 4.5). Obviously, the rate of evaporation was much higher on the hot than the cold day.

Table 4.5  AVERAGE AMOUNT OF WATER EVAPORATED DURING 3 DAYS

<table>
<thead>
<tr>
<th>Period</th>
<th>Cold day (Below 23°C)</th>
<th>Hot day (Above 23°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water (ml)</td>
<td>Temp. (°C)</td>
</tr>
<tr>
<td>Day 1</td>
<td>25.0</td>
<td>18°</td>
</tr>
<tr>
<td>Day 2</td>
<td>34.0</td>
<td>22°</td>
</tr>
<tr>
<td>Day 3</td>
<td>31.0</td>
<td>20°</td>
</tr>
<tr>
<td>Average</td>
<td>30.0</td>
<td></td>
</tr>
</tbody>
</table>

The results of the evaporation pan test helped the researcher to determine the minimum amount of water that had to be irrigated on the plants on a daily basis. Water was irrigated into the planting pots in winter (100ml per pot) and summer (150ml per pot).

4.6 PLANT GROWTH AND DEVELOPMENT

4.6.1 Plant height

Plant height is an indicator of growth-enhancing properties (O’Dell et al., 2007; Gerber, 2010), as well as the possibility of chemical agents against waste ash that may cause stunted growth in maize plants. Plant heights were evaluated in different growth stages, namely the development of leaves, silking and tasselling (Du Plessis, 2003). The influence of the different soil mixes (additives) on plant growth, particularly plant height, was detected from germination until the last stage of silking and tasselling.

The mean plant height (cm) of Zea Mays differed significantly between winter and summer. The height of plants growing in summer were taller compared to that of plants growing in winter for all the additives selected as indicated in Figure 4.10.

In both seasons (winter and summer), the tallest plant was that with prescribed fertilizer and the shortest plant was that with plastic ash in summer, whereas those with waste ash and plastic ash in winter were both the shortest. The mean height at 18 days was taken as the initial measurement after all seeds germinated producing the plants (Table 4.6).
Figure 4.10  MEAN HEIGHTS AFTER 18 DAYS: COMPARISON BETWEEN WINTER AND SUMMER

Table 4.6  MEAN PLANT HEIGHTS AFTER 18 DAYS

<table>
<thead>
<tr>
<th>Additives</th>
<th>Mean plant height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Winter</td>
</tr>
<tr>
<td>Wood ash</td>
<td>3.0</td>
</tr>
<tr>
<td>Waste ash</td>
<td>2.8</td>
</tr>
<tr>
<td>Plastic ash</td>
<td>3.0</td>
</tr>
<tr>
<td>Without additives</td>
<td>5.4</td>
</tr>
<tr>
<td>Compost</td>
<td>10.0</td>
</tr>
<tr>
<td>Prescribed fertilizer</td>
<td>11.5</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
</tr>
<tr>
<td>Wood ash</td>
<td>4.0</td>
</tr>
<tr>
<td>Waste ash</td>
<td>4.3</td>
</tr>
<tr>
<td>Plastic ash</td>
<td>3.7</td>
</tr>
<tr>
<td>Without additives</td>
<td>7.8</td>
</tr>
<tr>
<td>Compost</td>
<td>12.5</td>
</tr>
<tr>
<td>Prescribed fertilizer</td>
<td>13.0</td>
</tr>
</tbody>
</table>

The height of plants supplemented with wood ash, waste ash and plastic ash were lower in winter and measured 3.0cm, 2.8cm and 3.0cm respectively, and between 4.0cm, 4.3cm and 3.7cm respectively in summer. The plants supplemented with compost measured 10cm in winter and 11.5cm in summer, and the prescribed fertilizer measured 11.5cm in winter and 13.0cm in summer (Figure 4.10 and Table 4.6). Some of the agronomic parameters were not
well established in the plants supplemented with the various ashes, for instance, the height of plants with no additives in the soil were highly varied between winter and summer (5.4cm and 7.8cm respectively).

*Figure 4.11  MEAN PLANT HEIGHT IN WINTER*

*Figure 4.12  MEAN PLANT HEIGHT IN SUMMER*

The overall difference between winter and summer plants without additives was very varied. In winter, growth was poor yet in summer, growth was moderate and the height of the plants was nearly double the height of those planted in waste ash. The poorest performers in plant height were waste ash, which measured 2.8cm in winter, and plastic ash, which measured 3.7cm in summer. The fertilizer additive produced the highest performer in both winter (137.0cm) and summer (174.5cm) (Figures 4.11 and 4.12).
Tables 4.7 and 4.8 depict the mean plant height as measured on 30, 60, 90 and 120 days after planting. These figures clarify how *Zea Mays* in soil with different additives varied in plant height from 30 to 120 days. From the graph shown in Figure 4.12, it is evident that the prescribed fertilizer and compost were the most beneficial for plant growth in summer and that plastic ash was the least beneficial. Figures 4.11 and 4.12 graphically show the trends presented in Tables 4.7 and 4.8.

**Table 4.7  MEAN PLANT HEIGHT IN WINTER**

<table>
<thead>
<tr>
<th>Additives</th>
<th>Mean height (cm) for maize plants at various intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>After 30 days 13 July - After 60 days 15 August - After 90 days 14 September - After 120 days 14 October - After 150 days 13 November</td>
</tr>
<tr>
<td>Wood ash</td>
<td>15.0 - 38.0 - 55.0 - 65.0 - 72.7</td>
</tr>
<tr>
<td>Waste ash</td>
<td>11.0 - 34.0 - 47.0 - 58.0 - 64.5</td>
</tr>
<tr>
<td>Plastic ash</td>
<td>8.0 - 23.0 - 45.5 - 51.0 - 59.6</td>
</tr>
<tr>
<td>Compost</td>
<td>20.0 - 57.5 - 97.0 - 119.5 - 128.4</td>
</tr>
<tr>
<td>Prescribed fertilizer</td>
<td>24.0 - 65.0 - 108.5 - 128.0 - 137.0</td>
</tr>
<tr>
<td>Without additives</td>
<td>16.0 - 38.5 - 75.0 - 98.5 - 107.5</td>
</tr>
</tbody>
</table>

**Table 4.8  MEAN PLANT HEIGHT IN SUMMER**

<table>
<thead>
<tr>
<th>Additives</th>
<th>Mean height (cm) of maize plants at various intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>After 30 days 9 October - After 60 days 10 November - After 90 days 9 December - After 120 days 16 January - After 150 days 15 February</td>
</tr>
<tr>
<td>Wood ash</td>
<td>21.0 - 46.0 - 60.0 - 80.0 - 84.6</td>
</tr>
<tr>
<td>Waste ash</td>
<td>15.0 - 40.5 - 58.5 - 65.0 - 69.3</td>
</tr>
<tr>
<td>Plastic ash</td>
<td>12.0 - 38.0 - 42.0 - 61.5 - 66.1</td>
</tr>
<tr>
<td>Compost</td>
<td>33.5 - 91.0 - 115.0 - 163.0 - 171.5</td>
</tr>
<tr>
<td>Prescribed fertilizer</td>
<td>35.0 - 88.5 - 123.0 - 164.5 - 174.5</td>
</tr>
<tr>
<td>Without additives</td>
<td>26.0 - 67.0 - 97.0 - 125.5 - 132.5</td>
</tr>
</tbody>
</table>

The top performing additives on 150 days (Tables 4.7 and 4.8 and Appendix C) in both the summer and the winter planting were as follows (from highest to the lowest plant height): prescribed fertilizer (174cm), compost (171cm) and without additives (132cm) as shown in Appendix C for a variety of agronomic parameters. The poorest performing additives
regarding plant height were as follows: plastic ash with the height of 59.0cm in winter and 66.0cm in summer, whereas waste ash and wood ash had heights of 69.3cm and 84.6cm respectively.

Waste ash differed significantly from the top performing additives. The plants supplemented with waste ash were struggling to grow from the first growth stage until the last stage. The evaluation of plant height at two different growth stages was a very good indication of stem growth in length compared to stem and foliage and the total maize plant.

4.6.2 Measurement of stem circumference

The plant stem is that part of the plant that holds up other structures, such as the leaves and flowers. Stems carry water and minerals up from the roots to the leaves to help with photosynthesis and take food back down to be stored and distributed to the plant as it has need (Du Plessis, 2003).

<table>
<thead>
<tr>
<th>Additive</th>
<th>Plant 1 (cm)</th>
<th>Plant 2 (cm)</th>
<th>Plant 3 (cm)</th>
<th>Plant 4 (cm)</th>
<th>Average (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood ash</td>
<td>7.1</td>
<td>5.8</td>
<td>6.1</td>
<td>5.0</td>
<td>6.00</td>
</tr>
<tr>
<td>Waste ash</td>
<td>5.2</td>
<td>6.4</td>
<td>5.4</td>
<td>6.2</td>
<td>5.80</td>
</tr>
<tr>
<td>Plastic ash</td>
<td>4.5</td>
<td>4.4</td>
<td>5.8</td>
<td>6.9</td>
<td>5.40</td>
</tr>
<tr>
<td>Compost</td>
<td>7.7</td>
<td>9.1</td>
<td>8.7</td>
<td>9.0</td>
<td>8.63</td>
</tr>
<tr>
<td>Prescribed fertilizer</td>
<td>9.0</td>
<td>7.9</td>
<td>9.4</td>
<td>9.3</td>
<td>8.90</td>
</tr>
<tr>
<td>Without additives</td>
<td>8.5</td>
<td>7.3</td>
<td>7.9</td>
<td>7.5</td>
<td>7.80</td>
</tr>
</tbody>
</table>

There are notable differences when the plants are compared with those planted in prescribed fertilizer, compost and wood ash. These provided a more consistent growth medium for the plants. Based on the circumference values provided in Table 4.10, the differences within the four plants in a pot are less for the latter additives (1.2cm, 1.1cm and 1.3cm respectively) than the four plants growing in the mix without additives (2.3cm), waste ash (2.3cm) or plastic ash (1.6cm).

The average stem circumference varied between winter and summer (Tables 4.9 and 4.10). Compost and the prescribed fertilizer produced slight differences in stem growth in winter and
summer compared to other additives (wood ash, waste ash and plastic ash), which had a higher difference in stem circumference between winter and summer with a consistently larger circumference in summer.

Table 4.10 STEM CIRCUMFERENCE OF EACH PLANT IN DIFFERENT PLANTING POTS AFTER 150 DAYS IN SUMMER

<table>
<thead>
<tr>
<th>Additive</th>
<th>Plant 1 (cm)</th>
<th>Plant 2 (cm)</th>
<th>Plant 3 (cm)</th>
<th>Plant 4 (cm)</th>
<th>Average (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood ash</td>
<td>5.8</td>
<td>6.1</td>
<td>4.8</td>
<td>5.3</td>
<td>5.50</td>
</tr>
<tr>
<td>Waste ash</td>
<td>4.2</td>
<td>6.3</td>
<td>5.5</td>
<td>4.0</td>
<td>5.00</td>
</tr>
<tr>
<td>Plastic ash</td>
<td>5.5</td>
<td>3.9</td>
<td>4.5</td>
<td>4.1</td>
<td>4.50</td>
</tr>
<tr>
<td>Compost</td>
<td>8.6</td>
<td>8.3</td>
<td>7.5</td>
<td>8.1</td>
<td>8.13</td>
</tr>
<tr>
<td>Prescribed fertilizer</td>
<td>8.7</td>
<td>8.2</td>
<td>9.2</td>
<td>8.0</td>
<td>8.53</td>
</tr>
<tr>
<td>Without additives</td>
<td>7.2</td>
<td>5.0</td>
<td>7.3</td>
<td>6.1</td>
<td>6.40</td>
</tr>
</tbody>
</table>

It was observed that the plant stem in planting pots with prescribed fertilizer, compost and without additives were superior to those with waste ash, wood ash and plastic ash. The wood ash additive notably increased the plant stem circumference when comparing winter and summer values as indicated in Tables 4.9 and 4.10.

This also supports the fact that the wood ash had a moderate concentration of NPK (Nitrogen, Phosphorus and Potassium), particularly Nitrogen, when compared to other waste ashes. Fisher et al. (1987) substantiate that nitrogen effects plant growth, specifically plant height, size of stem and leaves. In this study, the concentration of Nitrogen and Phosphorus was decreasing in the order of fertilizer, compost, without additive, wood ash, waste ash and then the least in plastic ash.

4.6.3 Number of leaves
A plant is usually assigned a growth stage depending on the number of visible leaf collars present (O’Keeffe, 2009). In this study, the rate of plant growth was determined as described in Chapter 3 for each additive tested to analyse the progression of plant growth for each planting pot. The number of leaves produced by each growing plant was measured and recorded during the course of the study as shown in Tables 4.11 and 4.12.
Table 4.11  NUMBER OF LEAVES ON EACH PLANT AFTER 120 DAYS IN WINTER

<table>
<thead>
<tr>
<th>Additive</th>
<th>Plant 1</th>
<th>Plant 2</th>
<th>Plant 3</th>
<th>Plant 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood ash</td>
<td>11</td>
<td>10</td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>Waste ash</td>
<td>9</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Plastic ash</td>
<td>8</td>
<td>7</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Compost</td>
<td>15</td>
<td>13</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>Prescribed fertilizer</td>
<td>18</td>
<td>16</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>Without additives</td>
<td>11</td>
<td>13</td>
<td>12</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 4.12  NUMBER OF LEAVES OF EACH PLANT AFTER 120 DAYS IN SUMMER

<table>
<thead>
<tr>
<th>Additive</th>
<th>Plant 1</th>
<th>Plant 2</th>
<th>Plant 3</th>
<th>Plant 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood ash</td>
<td>14</td>
<td>11</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Waste ash</td>
<td>12</td>
<td>9</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Plastic ash</td>
<td>8</td>
<td>10</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Compost</td>
<td>18</td>
<td>15</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>Prescribed fertilizer</td>
<td>20</td>
<td>19</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Without additives</td>
<td>13</td>
<td>17</td>
<td>16</td>
<td>17</td>
</tr>
</tbody>
</table>

The number of leaves of each plant differs from the winter to the summer planting. Plants supplemented with the additive prescribed fertilizer had the most with an average of 20 leaves and 18 leaves in summer and winter respectively. The plants in the pot with compost as additive had an average of 18 leaves and 15 leaves in summer and winter respectively. These additives produced the highest number of leaves when compared to waste ash additives where the plants produced an average of 9 leaves in summer and 7 in winter. When the *Zea Mays* plants progressed through the growth stages, some of the earlier leaves fell off because of stem expansion and aging. This concurs with the findings of O’Keeffe (2009).

The results of this study, however, indicate that the plants in the pots with the plastic ash additive had leaves with little surface area. The leaves play an integral part in photosynthesis, as reported by Hoeft *et al.* (2000), thus their growth is an indication of the rate of...
photosynthesis. The plants growing with the plastic ash additive showed less growth compared to the wood ash and waste ash additives.

4.6.4 Colour of the leaves

The colour of the leaves often serves as a diagnostic feature in plants. For example, plants with purple leaves, instead of the normal green colour, most likely have a phosphorus deficiency (O’Keeffe, 2009). Leaf problems in plants that are deficient in nutrients or trace minerals are common and may lead to stunted growth, drying and discolouration. A number of factors including poor soil, insect damage, too much fertilizer, poor soil drainage or disease often cause plant deficiencies (O’Keeffe, 2009).

Table 4.13 COLOUR OF PLANT LEAVES AFTER 150 DAYS FOR WINTER AND SUMMER

<table>
<thead>
<tr>
<th>Additive</th>
<th>Winter</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood ash</td>
<td>Weak yellow</td>
<td>Dark green</td>
</tr>
<tr>
<td>Waste ash</td>
<td>Weak yellow</td>
<td>Weak yellow</td>
</tr>
<tr>
<td>Plastic ash</td>
<td>Yellowish</td>
<td>Weak yellow</td>
</tr>
<tr>
<td>Compost</td>
<td>Green</td>
<td>Strongly green</td>
</tr>
<tr>
<td>Prescribed fertilizer</td>
<td>Green</td>
<td>Strongly green</td>
</tr>
<tr>
<td>Without additives</td>
<td>Dark green</td>
<td>Green</td>
</tr>
</tbody>
</table>

The colour of the leaves changed inconsistently every week and the colours ranged from weak yellow, dark green, green and strong green as shown in Table 4.13. The leaves of each plant differed in colour, even within the same planting pot. As the plants grew upward, the leaves at the bottom of the plant changed colour from green to weak yellow, whilst some leaves were still green. This occurred mostly in winter planting, as well as for certain additives (waste ash). The data of the colour of the leaves were recorded on 150 days after planting, because it was regarded as the maturation stage.

4.6.5 Plant maturation (silking and tasselling)

The tassel is the male flowering structure of the maize plant and maize plants have separate male and female flowers (Hoeft et al., 2000; O’Keeffe, 2009). O’Keeffe (2009) mentioned that the only function of the male flower (the tassel) is to produce pollen to fertilize the female flower (the ear). According to Scott (2010), the number of pollen grains produced by a tassel is usually between 2 to 5 million, and since maize is a wind-pollinated plant, it produces
copious quantities of pollen. This increases the chance of a pollen grain landing on each silk thus increasing the chances of fertilization occurring.

In this study, the development of tasselling was recorded for all the *Zea Mays* planted as shown in Table 4.14. The first signs of the silking and tasselling stages started to show from 10 September 2013 for the first planting experiment (after 87 days for seed propagated for winter planting) and on the 26 November 2013 for the second planting experiment (after 80 days for seed grown for summer planting).

**Table 4.14** AVERAGE RATE OF TASSEL GROWTH PER WEEK FOR 3 WEEKS

<table>
<thead>
<tr>
<th>Additives</th>
<th>Winter planting cm/week</th>
<th>Summer planting cm/week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood ash</td>
<td>4.0</td>
<td>4.3</td>
</tr>
<tr>
<td>Waste ash</td>
<td>3.0</td>
<td>3.6</td>
</tr>
<tr>
<td>Plastic ash</td>
<td>2.8</td>
<td>3.5</td>
</tr>
<tr>
<td>Compost</td>
<td>6.0</td>
<td>7.6</td>
</tr>
<tr>
<td>Prescribed fertilizer</td>
<td>6.4</td>
<td>7.6</td>
</tr>
<tr>
<td>Without additives</td>
<td>5.0</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Figure 4.13 TASSEL DEVELOPMENT OF PLANTS WITH WASTE ASH ADDITIVE IN WINTER AND SUMMER FOR FIRST 5 WEEKS

The rate of silk and tassel development in the plants grown in plastic ash additives was the slowest, with the average rate being 2.8cm/week in winter and 3.5cm/week in summer. For the plants grown in soil with prescribed fertilizer, the average rate was 6.4cm/week in winter
and 7.6cm/week in summer thus attaining the highest average (Figure 4.13 and Table 4.14). Very close to this achievement, plants grown with the compost additive had an average rate of 6.0cm and 7.6cm in winter and summer respectively (Figure 4.14). Tasselling development was also slower for waste ash (3.0cm and 3.6cm in winter and summer respectively).

Figure 4.14  DEVELOPMENT OF SILKING ON PLANTS WITH COMPOST ADDITIVE

For plants, where the soil was supplemented with wood ash, waste ash and plastic ash, the tassels struggled to develop. The rate of tassel development of the plants supplemented with wood ash (4.0cm/week in winter and 4.3cm/week in summer) was a little faster than the waste ash (3cm/week in winter and 3.6cm/week in summer) and plastic ash (2.8cm/week in winter and 3.5cm/week in summer). Silking was therefore most developed in the plants planted with fertilizer and compost as additives.

The results of the rate at which tassel development took place also differed notably when comparing the plants grown in soil containing prescribed fertilizer as additive (6.4cm/week and 7.6cm/week in winter and summer respectively) with that of the waste ash additive (3.0cm/week and 3.6cm/week in winter and summer respectively) (Figures 4.15 and 4.16). The rate of tassel development among the tested additives shows increase in tassel development in the order of waste ash, plastic ash, wood ash, soil without additives, compost and fertilizer. The rate of development in plants grown in waste ash and plastic ash were almost the same. The rate of tassel and silk development was directly linked to the length of the cobs and the tassels that emerged from the leaf whorl.
The development of tassel in plants with the fertilizer and compost additives were most appropriate in both seasons (winter and summer). The average rate of tassel development when considering the waste ash additives, particularly plastic ash, was too low and the growth rate did not change in either winter or summer. Tassel development in plants with waste ash as additive was slightly better in summer.

In this study, the ear (a central cob with a group of flowers arranged cylindrically) development was difficult for the plants grown with plastic ash and waste ash additives. This indicates that fertilization did not happen properly in the case of these two additives. In the
summer, the wood ash additive was promising to be a good additive because silking appeared but the ear failed to grow. It can be assumed that the level of phosphorus, which is a mineral that plays a critical role in fruit development, was insufficient for these three additives (waste, plastic and wood ash) (Kogbe & Adediran, 2003).

4.7 CHEMICAL COMPOSITION OF WASTE ADDITIVES

The plants that feed us grow in the soil and keeping the soil healthy by maintaining soil quality is essential. Like all other forms of nature, the soil suffers from pollution (Agbede, 2008; O’Keeffe, 2009). The pollution of soil is common these days and it happens due to the presence of man-made elements (Aydin & Uzun, 2005; Agbede, 2008). How we dispose of our waste has become a growing cause for concern.

<table>
<thead>
<tr>
<th>Chemicals</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium, as CaO, % m/m [ICP]</td>
<td>16.41</td>
</tr>
<tr>
<td>Magnesium, as MgO, % m/m [ICP]</td>
<td>2.15</td>
</tr>
<tr>
<td>Potassium, as K$_2$O, % m/m [ICP]</td>
<td>2.66</td>
</tr>
<tr>
<td>Sodium, as Na$_2$O, % m/m [ICP]</td>
<td>0.99</td>
</tr>
<tr>
<td>Silica, as SiO$_2$, % m/m [HF Dehydration]</td>
<td>28.15</td>
</tr>
<tr>
<td>Loss on Ignition, % m/m [Gravimetric]</td>
<td>31.45</td>
</tr>
<tr>
<td>Iron, as Fe, % m/m [ICP]</td>
<td>2.23</td>
</tr>
<tr>
<td>Zinc, as Zn, mg/kg [ICP]</td>
<td>2550</td>
</tr>
<tr>
<td>Manganese, as Mn, mg/kg [ICP]</td>
<td>1173</td>
</tr>
<tr>
<td>Phosphorus, as P, mg/kg [ICP]</td>
<td>3643</td>
</tr>
<tr>
<td>Titanium, as Ti, mg/kg [ICP]</td>
<td>3109</td>
</tr>
<tr>
<td>Carbonates, as CO$_3$, % m/m [Shrotters]</td>
<td>14.00</td>
</tr>
</tbody>
</table>

NOTE: This analysis was performed at the accredited Als Global Laboratory on 26/09/2013 until 02/10/2013

Waste products that are not originally found in nature are full of chemicals and subsequently lead to soil pollution. The ecosystem becomes affected due to widespread soil contamination and most plants are unable to adapt when the chemistry of the soil changes in a short period of time (Agbede, 2008). The toxic chemicals present in the soil can decrease soil fertility
resulting in decreased crop yield. Apart from this, toxic chemicals also affect soil organisms, which then lead to an alteration in soil structure.

The chemical analysis entailed establishing the toxic to non-toxic variations in the waste ash. These were regulated by the composition of disposed solid waste. The test showed that the burning of waste does not degrade chemicals; rather it reduces the quantity of waste. The chemical analysis of household solid waste ash is indicated in the Table 4.15. Solid waste disposal practices, as was witnessed with the burning of waste, leave waste ash in the environment or veldt, which then leaves a number of chemicals that may retard plant growth.

The maximum acceptable level is the highest concentration at which diverse health effects cannot be seen in the exposed receptor (Wu et al., 2010). The chemical analysis was used to establish which chemicals exceed the permissible concentration in the environment. According to Kabata-Pendias (2011), the maximum allowable concentration of the following chemicals in the environment are: Iron (15.900mg/kg), Magnesium (325.000mg/kg), Zinc (2150mg/kg), Manganese (636mg/kg), loss on ignition (50%m/m), Titanium (2510mg/kg), Carbonates (2100mg/kg), Potassium (4%m/m) and sodium (3%m/m). In this study, only Zinc (2550mg/kg) and Titanium (3109mg/kg) (Table 4.15) are above the maximum acceptable concentration in the environment (humans and plant). The elemental form of Zinc is insoluble to plants even if is in the form of oxides, carbonates, phosphates and silicates that are not soluble, but its compounds as sulphates and chlorides can be extremely soluble (Kabata-Pendias, 2011). Apart from this, the pH also ranged from 4.0 to 5.5, indicating that the soil was slightly acidic, which is not a favourable environment for some household plants.

Many of these chemicals present in the waste additives are crucial for plant growth and some are regarded as nutrients of the soil. However, deficiencies and imbalances of these chemicals result in toxicity to soil fertility and plant growing, for example, a deficiency of phosphorus in the plant causes slow growth, stunted plants, purplish coloration on foliage of some plants and delayed maturity (O’Keeffe, 2009). The findings of this study concur with those of O’Keeffe (2009), because the agronomic parameters of the plants growing in the waste additives showed symptoms of phosphorus deficiency. On the other hand, Magnesium is required for photosynthesis since it is contained in the chlorophyll molecule. During conditions of deficiency, interveinal chlorosis (yellowing) in older leaves, curling of leaves upward along margins and stunted growth are observed (O’Keeffe, 2009). This suggests that the plastic ash
additive lacked magnesium because the plant growth revealed signs of magnesium deficiency (Table 4.15).

4.8 EFFECT OF ADDITIVES ON PLANT GROWTH

The planting of Zea Mays using different additives in the soil indicate variation between winter and summer. Generally, the conditions necessary for plant growth in the area were not as favourable in winter as in summer. This is due to inadequate temperatures, absence of rainfall in winter, the concentration of chemicals present on the study site and the shortage of those plant nutrients, which support plant growth. Mostafa and Derbala (2013b) reported similar findings.

The use of fertilizer and compost in planting Zea Mays had a good effect by supporting plant growth. However, in comparison with compost, as a secondary product of solid waste, fertilizer promoted plant height with 7 units in summer and 3 units in winter (Figure 4.17). On the other hand, all waste ash additives showed a lack of certain nutrients that support plant growth. The height of the plants grown with wood ash, waste ash and plastic ash additives were low compared to the plant height of those grown with compost and fertilizer as additives (Appendix C). The plant height of the plants grown with plastic ash as additive was the lowest (59.6cm and 66.1cm in winter and summer respectively), followed by waste ash (64.5cm and 69.3cm in winter and summer respectively) and wood ash (72.7cm and 84.6cm in winter and summer respectively). The plant height for the fertilizer additive (137cm and 174.5cm in winter and summer respectively) was far higher than that for the waste ashes (Appendix C).

The rate of plant growth varied from poor in winter to good in summer for most additives except for plastic ash and wood ash (Figure 4.17). Costa et al. (2002), Kogbe and Adediran (2003) and Lomer et al. (2012) indicated that Nitrogen, among the key nutrients (NPK) needed by plant, has a major effect on plant growth. Nitrogen, being the most stimulating factor of plant growth, was deficient in all the waste ash additives, which resulted in a very low mean rate of plant growth. Cakmak (2000) and Hafeez et al. (2013) found that Zinc deficiency in plants resulted in stunted growth. Jones (2003) indicated that Zinc is closely related to the nitrogen metabolism pathway of plants, thus causing a reduction in protein synthesis in Zinc deficient plants. Moreover, Nitrogen and Zinc deficiency affects the absorption of nutrients and water from the soil, resulting in growth and yield reduction in the plant.
In this study, waste ash and plastic ash are the additives that were lacking in Nitrogen and Zinc being the nutrients that support plant growth. Figure 4.18 shows the results of all the selected agronomic parameters representing plant growth for each additive tested. This is in accordance with the findings of Cakmak (2000), Jones (2003) and Hafeez et al. (2013).

The results of the soil fertility test (Table 4.1) indicate that the soil of the study site contained the necessary nutrients, which are fundamental for plant growth. This was confirmed by the
use of a planting pot without additives. The plants growing in the pot without additives (soil only) had been supported by the nutrients present in the soil.

The only supplement for growth was water in the form of irrigation and rainfall. However, the observed agronomic parameters (Figures 4.17, 4.18, 4.19 and Appendix C) indicate that there were significant differences between the planting pots without additives as opposed to the waste ash additive. This suggests that the use of waste additives reacted negatively in the soil by suppressing the growth of the plants. The addition of waste ash in the soil also has a negative impact on the environment (Figure 4.19).

![Image](image.jpg)

*Figure 4.19 MAIZE PLANT HEIGHT AFTER 8 WEEKS FOR VARIOUS SOIL ADDITIVES IN SUMMER*

### 4.9 CONCLUSION

The maize plant (*Zea Mays*) supplemented with the additives, waste ash and plastic ash, were significantly lower in almost all selected agronomic parameters compared to compost and prescribed fertilizer. The height of the plants supplemented with a wood ash additive was promising to be better than the other ashes. The differences between selected agronomic parameters, particularly plant height, for the prescribed fertilizer additive was significantly
higher in the summer planting and did not differ significantly from the winter planting at the maturation stage. The winter planting results were different from the summer planting results due to the seasonal weather conditions.
Chapter 5
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

This study concerned evaluating the impact of household solid waste disposal practices on plant growth in the rural areas of UThukela District Municipality (UTDM). This was achieved by collecting waste from selected households, conducting scientific tests of soil quality and waste ashes, planting Zea mays in different soil mixes and monitoring plant growth. In this chapter, the findings of the research are summarised, recommendations are made for the management of waste in rural areas by municipalities and considerations are noted with further research in mind.

Unregulated solid waste disposal is not a new phenomenon in the UTDM society. The increase in the human population in rural areas was accompanied by an increase in environmental problems experienced by the community because the waste had multiplied. The irregular and inadequate collection and management of household solid waste in the rural areas of UTDM left the residents, through sheer necessity, to dispose of the waste using various practices, which were not entirely environmentally friendly. In particular, the waste ended up being dumped in the open veldt and then burned, merely to dispose of it.

5.2 SUMMARY OF FINDINGS

Inadequate waste disposal facilities in rural areas cause problems for the local municipality, because it is their responsibility to collect, transport and dispose waste. This research revealed that the people in rural areas have adopted disposal practices, which are not acceptable to the environment, thus creating problems to the vegetation and plant growth. The literature reviewed for the study focussed on the disposal household solid waste and management practices in KwaZulu-Natal and the UTDM, the background of growing maize, the implication of waste disposal practices on the environment and the effects of waste disposal on the growth of common plants, such as maize (Chapter 2).
The detailed methodology for the study was explained that included descriptions of the data collection and the techniques used, the experiment designed and the planned analyses that would achieve the research objectives (Chapter 3). The reporting of the results and the discussion of the findings of the study included the composition of the solid waste collected on the study sight, soil fertility testing and the chemical analysis of waste ash, measurement of selected agronomic parameters and the evaluation of the impact of different waste ashes on maize plant growth (Chapter 4). The major findings of the study are outlined below according to the objectives initially formulated.

5.2.1 Characteristics of household solid waste
Municipal solid waste (MSW) contains various types of waste including biodegradable and non-biodegradable waste. Characterisation of waste is significant at the household level, because it assists in waste management hierarchy, which gives priority firstly to prevention, secondly to the recovery of materials, thirdly to incineration, and lastly land filling and burning of waste.

Household solid waste was collected from the residents living in the UTDM using waste bags provided to each selected family. A demonstration was given of how to categorise waste as renewable and as non-renewable. Waste collected in this study included utensils, corrugated iron, broken branches of trees, batteries, used nappies, plastics, old food cans, already burnt waste ash, plastic ash, wood ash, food waste, old dishes and old tins and disposable material. Some of the waste materials collected were re-used for the planting experiment, like old dishes and utensils to serve as planting pots. The planting experiment entailed the evaluation of the impact of various waste ashes on the growth of a common maize plant (Zea mays) that is grown in an area of the UTDM.

Since the rural areas of the UTDM have no proper disposal site, prevention will be a viable alternative. Material recovery is feasible if waste characterisation has been done properly at household level.

5.2.2 Current soil fertility of the study site
Determination of soil fertility was done to evaluate the chemical content of the soil that sustains plant growth. The mineral nutrients provide plant habitat and result in lasting constant yields of high quality. The soil fertility test subsequently indicated that fertile soil has the following properties, which corresponds to the soil of the study area:
• It is rich in the nutrients necessary for basic plant sustenance.
• It contains soil organic matter that improves the structure of the soil and soil moisture retention.
• The soil pH is in the range 6.0 to 6.8 for most plants but some prefer acid or alkaline conditions.
• Microbial activities and the organic matter present improve the soil structure and promote moisture retention.

5.2.3 Toxicity and composition of waste ash collected from households
According to the literature, household solid waste contains toxic and non-toxic material. Over and above that, some chemicals remain active in the waste ash even though the waste had been burnt. Waste ashes collected at the UTDM contain various types of chemicals, of which some have a negative impact on the environment when at their maximum concentration. Zea mays (maize), as the common plant of this region, absorbs the constituents in the soil, which include chemicals exposed in the soil of the growing plant. The study revealed that waste ash is composed of various chemicals of which some affect plant growth due to their toxicity. The effect is two-fold:
• Disposal of waste ash additives in the soil introduces chemicals, which are deposited in the top soil and subsequently affect plant growth, thus decreasing crop yield.
• The influence of different waste ashes (plastic, waste and wood ash) in the soil affects the growth of the plant by perturbing the development of certain agronomic parameters. The chemicals found, in the test of waste ashes, with the highest concentration were Titanium (3109mg/kg) and Zinc (2550mg/kg), which are above the maximum acceptable concentration in the environment (humans and plant).

5.2.4 Effect of disposed ash on plant growth of maize seeds
This study revealed that household solid waste disposal practices in rural areas of the UTDM are not environment friendly. This was supported by the impact of the waste ash additives on the growth of the planted maize seeds. Soil mixes with waste ashes (wood, waste and plastic ash) introduce a negative effect to the soil, which then poses as a threat to plant growth. The results of this study corroborate this statement based on the specific results concerning the germination, plant height, stem circumference, number of leaves, silking and tassel development.
The trend found was that the negative impact of wood ash, waste ash and plastic ash on plant growth increased in this order. Of these three waste ashes, the wood ash additive affected plant growth the least. Notwithstanding, in the first three weeks in both the summer and the winter, the plants in the planting pot supplemented with wood ash showed dryness (dehydration). All the waste ash additives affected plant growth negatively when compared to the seeds grown in natural soil (soil only) and those planted in soil with the compost or fertiliser additives.

Plants with soil only (no additive added) showed a more normal growth rate as compared to all the waste ashes. The growth in this planting pot (soil only) concurs with results of the soil fertility test, which indicated that the soil from the study site has sufficient nutrients to support plant growth. In addition, all growth stages of these plants (soil only) were able to develop.

The waste and plastic ash additives showed a slower growth rate in plant height, stem circumference, number of leaves, silking and tassel development. In some plants, certain parameters did not develop at all. Comparing additives of the waste ashes with the compost, fertiliser and soil without additives helped to identify that chemicals contained in waste ashes react badly with soil minerals, which affected plant growth negatively.

The climate at UTDM varies distinctively from winter to summer. Planting Zea mays at the UTDM in summer had shown significant differences from those planted in winter, in spite of using a greenhouse net in winter to overcome frost and extreme low temperatures. The seeds planted in soil with wood ash as additive and those without any additive showed the largest variations from winter to summer.

5.2.5 Ways for UTDM to improve the management of solid waste

In the section on recommendations, the ways and means for the UTDM to improve the management of solid waste to effect reduction, re-use, recycling and recovery, are discussed.

5.3 CONCLUSIONS

Based on the results accrued from the collected data on the waste disposal practices in the rural areas of UThukela District Municipality, the following came to the fore:
• The rural areas do not enjoy any services from the UTDM regarding the removal and disposal of household waste in their region due to the poor road infrastructure for the vehicles to access these areas.

• The residents use various crude disposal methods to deal with their household waste, which pose a threat to the environment.

• The residents use various crude disposal methods to deal with their household waste, like burning of waste and dumping it in the open veldt, posing a threat to the environment. The waste ashes contaminate the surrounding area, which is used for the planting of crops.

• The residents participating in the study were more than willing to separate their waste into biodegradable and non-biodegradable waste.

• The uncontaminated soil within and around the selected study area is fertile and has sufficient nutrients for healthy and effective plant growth.

• The additives of wood ash, waste ash and plastic ash contaminated the soil to various degrees and negatively affected the growth of the maize seeds used in the experiment.

• An analysis of the chemical status of the various waste ashes revealed the presence of toxic content.

• In the case where compost and fertilizers were used as additives and the soil without added additives in the experiment, healthy growth could take place, however, the germination and growth period to produce adult plants differed seasonally in the winter and the summer.

5.4 RECOMMENDATIONS FOR MANAGEMENT OF SOLID WASTE

Solid waste disposal practices in rural areas of KwaZulu-Natal particularly UThukela District Municipality (UTDM) need attention from all stakeholders (officials from government, municipality and community). Their unwanted practices mentioned below have to be discouraged and banned completely because research revealed that it has a negative impact on the environment:

• Burning of waste in rural or any areas has to be banned completely, and indiscriminate disposal of wood ash from wood fire should be avoided.
- UThukela District Municipality (UTDM) together with their local Municipalities has to review their solid waste disposal practices and to initiate and encourage re-using, recycling and reducing waste especially in the rural areas where wastes are not collected by the municipality.

- UTDM should promote and strengthen the Siyazenzela Domestic Waste Management Programme as a viable and working alternative to all five local municipalities, but particularly at Indaka, Imbabazane and Okhahlamba local municipality because these areas are highly dominated by rural areas.

- The intervention of waste management by Extended Public Works Project (EPWP) is appreciated, but it is insufficient because they target areas, such as schools and places where rural people regularly meet (tuck-shops complex), thus not reaching remote households.

- Effective allocation of funds to the Local Department of Solid Waste of the municipality should be prioritised.

- The Department of Environmental Affairs (DEA), the Traditional Councillors (Inkosi/Induna) and the Ward Councillors should play pivotal role in calling community meetings and summits to alert people about the effect of their waste disposal practices on the environment. It has been suggested that there should be a zero rate of land contamination with waste burnt ashes. This is because waste ashes affect plant growth and it is therefore susceptible to cause over-grazing with the consequence of soil erosion to the area affected.

- KZN-Provincial Department of Agriculture and Environmental Affairs, the UTDM and its local Municipalities should provide environmental awareness campaign among the rural residents and emphasise the importance of the management of household solid waste. It would provide job creation and would alleviate poverty through reclaiming that leads to recycling, re-using and recovery.

- The UTDM and its Local Municipalities must facilitate training for rural farmers on how to minimise waste by making compost (rich in plant nutrients for crops).

- The UTDM should support and promote employment and economic empowerment opportunities of community cooperatives, through using product re-use and recycling material.
• The local municipalities should provide at least one waste bin to a rural household.
• The waste separation at the source should be initiated at household level, where two different colour bags are provided to separate biodegradable and non-biodegradable waste.
• The UTDM should established drop-off centres for recyclable material; and the people who comply with this should be awarded with a food voucher at nearby food outlets.
• The Provincial Department, District Municipality and Local Municipality must ensure that the Integrated Waste Management Plan is implemented and strictly adhered to at local municipality level.

5.5 RECOMMENDATIONS FOR FUTURE RESEARCH

Further research is proposed to evaluate all environmental impacts of waste disposal practices, not only those for plant growth. The household solid waste disposal practices in rural areas need more attention as research conducted based on rural areas are very limited to date. The health risk caused by burnt waste ashes in the food chain and the impact of household solid waste disposal practices on air and water quality require urgent investigation.
REFERENCES


Appendix A

PERMISSION TO CONDUCT ENVIRONMENTAL RESEARCH

UThukela District Municipality
16 July 2012

S. A. Khumalo
P. O. Box 2471
BEROVILLE
3350

Sir

PERMISSION TO CONDUCT ENVIRONMENTAL RESEARCH IN RURAL AREAS OF UTHUKELA DISTRICT MUNICIPALITY

Permission is hereby granted to you to conduct environmental research in the following areas of Uthukela District Municipality:

1. Emmambithi/Ladysmith Local Municipality – Driefontein Complex
2. Imbabaani Local Municipality – Emangweni
3. Ochshamba Local Municipality – Emmaus

Yours faithfully

[Signature]

EXECUTIVE DIRECTOR: HEALTH & ENVIRONMENTAL SERVICES
Appendix B

RESULTS OF THE SOIL FERTILITY ANALYSIS
CLIENT DETAILS

Khumalo Sabelo
P.O Box 471 Bergville
3350
Mobile: 078 224 9465

SUMMARY OF ANALYTICAL RESULTS
(These results may not be used in litigation)

Batch 378  Year: 2013  Printed: 3/07/2013

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<th>Lab number</th>
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<th>K mg/L</th>
<th>Ca mg/L</th>
<th>Mg mg/L</th>
<th>Exch. acidity cmol/L</th>
<th>Total cations cmol/L</th>
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**COMMENTS:**

1. Recommended rates of fertilizer and lime for the relevant crops are reported on the following pages. No recommendation will be given for crops not entered on the submission form.

2. Recommendations are not provided for subsoil samples.

3. It is assumed that samples submitted for crops and for the establishment of pastures were taken from the top 15 cm of soil. For the maintenance of established pastures, a sampling depth not exceeding 10 cm is assumed.

4. It is assumed that the lime to be used has a neutralising value equal to 75% of that of pure calcium carbonate. Dolomitic lime is recommended if soil Mg levels are low, and calcitic lime, if soil Mg exceeds 0.6 x soil Ca. Where Mg is sufficient, but not excessive, either type of lime may be used. If lime is not necessary, but the soil Mg level is suboptimal for the intended crop, this is indicated under the "Lime type" heading with the comment "low Mg". Consult your advisor for the most cost-effective method of improving Mg status.

5. Phosphorus recommendations are based on a water-soluble P source.

6. The recommendations are based on the assumption that the soil sample is truly representative of the land and that other growth factors are not limiting.

7. Organic carbon, total nitrogen and clay percentage, estimated by mid-infrared (MIR) spectroscopy, is given for most samples. MIR measurements should be viewed as reasonably reliable estimates. Actual C, N and clay percentages (as well as S concentrations) can be determined (at extra cost) on request.
**DRY BEAN: IRRIGATED**

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<th>Target soil test mg/L</th>
<th>Req. P kg/ha</th>
<th>Sample soil test mg/L</th>
<th>Target soil test mg/L</th>
<th>Req. K kg/ha</th>
<th>Sample acid. sat. %</th>
<th>PAS %</th>
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Sample soil test and sample acid saturation reflect the soil test values of the sample submitted. Required P and required K (coloured red) are the amounts of P and K required to raise the soil test to the target value. Lime required (coloured red) is the amount of lime needed to decrease the soil acid saturation to the permissable acid saturation (PAS).

**MANAGEMENT GUIDELINES**

1. LIME, if required, should be applied at least one to two months before planting. It is assumed that the lime will be incorporated to a depth of 20 cm. Thorough incorporation is essential: discing followed by ploughing is recommended.
2. Where soil test P levels are considered adequate, but are less than 120 mg/L, a starter application of 20 kg P/ha has been recommended to promote initial plant growth.
3. Where the soil P test of a sample is abnormally high (>120 mg/L), and the sample is truly representative of the whole field, no fertilizer P should be applied until test levels indicate a P requirement.
4. This crop requires 20 - 30 kg S/ha. This can usually be supplied from the atmosphere and by the mineralization of organic S in soils, but supplementary S fertilizers may be necessary on sandy soils, where sulphate is lost by leaching.

**FERTILIZER OPTIONS**

The following are fertilizer options (given in bags/ha) using DAP, MAP, Double Supers, 2:3:4(38), KCl, LAN and urea. Your local fertilizer adviser can provide additional fertilizer options. The quantities recommended are those for a complete growing season and the management guidelines on the previous page/s should be considered when scheduling applications.

---

**Sample F8102 Yield target (t/ha) 1.0**
- If DAP was used, too much nitrogen would be supplied.
- If MAP was used, too much nitrogen would be supplied.
- 11.4 bags/ha Single Supers (10.5%P); 0.4 bags/ha KCl; 2.9 bags/ha LAN or 1.7 bags/ha urea.
- If 234 was used, too much nitrogen would be supplied.

---

**Sample F8102 Yield target (t/ha) 2.0**
- If DAP was used, too much nitrogen would be supplied.
- If MAP was used, too much nitrogen would be supplied.
- 11.4 bags/ha Single Supers (10.5%P); 0.4 bags/ha KCl; 5.7 bags/ha LAN or 3.5 bags/ha urea.
- If 234 was used, too much nitrogen would be supplied.

---

**Sample F8102 Yield target (t/ha) 3.0**
- If DAP was used, too much nitrogen would be supplied.
- If MAP was used, too much nitrogen would be supplied.
- 11.4 bags/ha Single Supers (10.5%P); 0.4 bags/ha KCl; 8.6 bags/ha LAN or 5.2 bags/ha urea.
- If 234 was used, too much nitrogen would be supplied.
MAIZE GRAIN: IRRIGATED

<table>
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Sample soil test and sample acid saturation reflect the soil test values of the sample submitted. Required P and required K (coloured red) are the amounts of P and K required to raise the soil test to the target value. Lime required (coloured red) is the amount of lime needed to decrease the soil acid saturation to the permissible acid saturation (PAS).

MANAGEMENT GUIDELINES

(1) LIME, if required, should be applied at least one to two months before planting. It is assumed that the lime will be incorporated to a depth of 20 cm. Thorough incorporation is essential: discing followed by ploughing is recommended.

(2) In order to increase the time between liming operations, it is often advisable to apply more lime than recommended above. Liming to 10% acid saturation rather than 20% is a sound policy for maize lands.

(3) Where soil test P levels are considered adequate, but are less than 120 mg/L, a starter application of 20 kg P/ha has been recommended to promote initial plant growth.

(4) At least 20 kg of the recommended P should be applied in the band at planting.

(5) Where the soil P test of a sample is abnormally high (>120 mg/L), and the sample is truly representative of the whole field, no fertilizer P should be applied until test levels indicate a P requirement.

(6) Nitrogen recommendations given above should be used as a guideline only as there are many situations where lower N rates are more cost-effective. Details are given in the leaflet "Nitrogen fertilization: Allowing for N mineralization and residual N" which is available from Alan Manson (033-3559100).

(7) On all soils, applications of N should be split in order to improve efficiency of N use and minimise soil acidification. This is especially important on soils that tend to waterlog as well as on sandy soils. Topdressed N should be applied when the plants are knee high.

(8) Ensure that the total combined N and K applied in the band at planting does not exceed 80kg/ha.

(9) N applications may be reduced by 40 kg/ha if the previous crop was soybean that yielded 2-3t/ha.

(10) This crop requires 20 - 30kg S/ha. This can usually be supplied from the atmosphere and by the mineralization of organic S in soils, but supplementary S fertilizers may be necessary on sandy soils, where sulphate is lost by leaching.

(11) If subsoil K (anywhere between 15 and 60cm deep) is greater than 100mg/L and the sample density is greater than 1.35g/mL, the K recommendation can be decreased by 50kg/ha.

FERTILIZER OPTIONS

The following are fertilizer options (given in bags/ha) using DAP, MAP, Double Supers, 2:3:4(38), KCl, LAN and urea. Your local fertilizer adviser can provide additional fertilizer options. The quantities recommended are those for a complete growing season and the management guidelines on the previous page/s should be considered when scheduling applications.

Sample F8102 Yield target (t/ha) 12.0

- If DAP was used, too much nitrogen would be supplied.
- 5.5 bags/ha MAP; 2.4 bags/ha KCl; 12.1 bags/ha LAN or 7.4 bags/ha urea.
- 11.4 bags/ha Single Supers (10.5%P); 2.4 bags/ha KCl; 14.3 bags/ha LAN or 8.7 bags/ha urea.
• 9.4 bags/ha 2:3:4(38); 11.5 bags/ha LAN or 7.0 bags/ha urea. The 2:3:4 would supply more than sufficient K.
**SPINACH: IRRIGATED**

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Sample soil test and sample acid saturation reflect the soil test values of the sample submitted. Required P and required K (coloured red) are the amounts of P and K required to raise the soil test to the target value. Lime required (coloured red) is the amount of lime needed to decrease the soil acid saturation to the permissable acid saturation (PAS).

**MANAGEMENT GUIDELINES**

1. Lime, if required, should be applied at least one to two months before planting. It is assumed that the lime will be incorporated to a depth of 20 cm. Thorough incorporation is essential: discing followed by ploughing is recommended.

2. Where P levels are considered adequate, but are less than 120 mg/L, an application of 40 kg P/ha has been recommended to ensure adequate growth.

3. Where the soil P test of a sample is abnormally high (>120 mg/L), a response to P fertilizer is unlikely. However, P fertilizer may be applied to ensure that adequate P is available over the entire area to be cropped.

4. To ensure high yields, it is recommended that 30 - 40 kg/ha of sulphur be applied at establishment or soon thereafter.

5. Consult your adviser on the use of micronutrients such as zinc, boron and molybdenum.

**FERTILIZER OPTIONS**

The following are fertilizer options (given in bags/ha) using DAP, MAP, Double Supers, 2:3:4(38), KCl, LAN and urea. Your local fertilizer adviser can provide additional fertilizer options. The quantities recommended are those for a complete growing season and the management guidelines on the previous page/s should be considered when scheduling applications.

Sample F8102 optimum yield
- 25.0 bags/ha DAP; 10.4 bags/ha KCl If DAP was used to supply the recommended P, it would supply more N than required.
- 22.7 bags/ha MAP; 10.4 bags/ha KCl If MAP was used to supply the recommended P, it would supply more N than required.
- 47.6 bags/ha Single Supers (10.5%P); 10.4 bags/ha KCl; 7.1 bags/ha LAN or 4.3 bags/ha urea.
- 39.4 bags/ha 2:3:4(38) The 2:3:4 would supply more than sufficient N and K.
Appendix C

AGRONOMIC PARAMETERS AFTER 150 DAYS
### MEASUREMENTS OF DIFFERENT AGRONOMIC PARAMETERS AFTER 150 DAYS

<table>
<thead>
<tr>
<th>Additives</th>
<th>Plant height (cm)</th>
<th>Stem circumference (cm)</th>
<th>Number of leaves</th>
<th>Colour of leaves</th>
<th>Length of tassel growth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Winter</td>
<td>Summer</td>
<td>Winter</td>
<td>Summer</td>
<td>Winter</td>
</tr>
<tr>
<td>Wood ash</td>
<td>72.7</td>
<td>84.6</td>
<td>5.5</td>
<td>6.0</td>
<td>10</td>
</tr>
<tr>
<td>Waste ash</td>
<td>64.5</td>
<td>69.3</td>
<td>5.0</td>
<td>5.8</td>
<td>8</td>
</tr>
<tr>
<td>Plastic ash</td>
<td>59.6</td>
<td>66.1</td>
<td>4.5</td>
<td>5.4</td>
<td>8</td>
</tr>
<tr>
<td>Compost</td>
<td>128.4</td>
<td>171.5</td>
<td>8.1</td>
<td>8.6</td>
<td>14</td>
</tr>
<tr>
<td>Prescribed fertilizer</td>
<td>137.0</td>
<td>174.5</td>
<td>8.5</td>
<td>8.9</td>
<td>16</td>
</tr>
<tr>
<td>Without additive</td>
<td>107.5</td>
<td>132.5</td>
<td>6.4</td>
<td>7.8</td>
<td>12</td>
</tr>
</tbody>
</table>
Appendix D

PERMISSION FROM AMANGWANI TRIBAL AUTHORITY
Amangwane Tribal authority
Bergville
3350
Date: 04 July 2012

TO WHOM IT MAY CONCERN

RE: PERMISSION OF DOING RESEARCH IN AMANGWANE COMMUNITIES.

Inkosi/ Chief of Amangwane, here to affirm and grant the permission for SA Khumalo, 46930078, student of University of South Africa to undertake his study, since it will help the community at the end.

Any one should allow him or his colleagues in doing this study in the above stated communities.

Kind Regards.

Inkosi M Hlongwane